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EFFECTS OF OPERATING THE MT. ELBERT PUMPED-STORAGE POWERPLANT ON TWIN LAKES, COLORADO: 1981 REPORT OF FINDINGS

December 1982

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James F. LaBounty and James J. Sartoris

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16. ABSTRACT

A series of studies is being performed to identify and quantify changes that occur in the aquatic ecology of Twin Lakes, Colorado, because of the Mt. Elbert Pumped-Storage Powerplant, which began operation in August 1981. The results presented here are part of the investigations being done by the Bureau of Reclamation on the ecological effects of pumped-storage construction and operation. These studies have been going on since 1971. The Twin Lakes and the powerplant are being used for the primary field investigations. Although it is too early to identify any ecological changes, this report presents results of studies done in 1981. These results, along with those from other studies done since 1971 when the project began, are being used to define the preoperational limnology of Twin Lakes.

Twin Lakes are a pair of dimictic, connected, montane, drainage lakes of glacial origin. Based on seven limnological parameters, the lakes are classified as oliogtrophic lakes. Maximum water temperatures of 18 °C were recorded in August 1981 for both lakes. The lowest measured dissolved oxygen concentration during 1981 was 1.7 mg/L at the bottom of the lower lake in October. The pH ranged between 6.5 and 8.3, and conductivity levels were between 69 and 102 μS/cm. Total phosphorous concentrations during 1981 ranged from less than 1 μg/L, which has been the case most of the time during the past 6 years, to a high of 31 μg/L. Nitrate nitrogen concentrations ranged from less than 10 to 170 μg/L. Average daily primary productivity rates during 1981 ranged from a low of 84 mg C/(m^2·d) in the upper lake during March to a high of 126.6 mg C/(m^2·d) in the lower lake during May. Chlorophyll *a* concentrations during 1981 ranged from a mean concentration of 0.4 mg/m^3 in the lower lake during May to a mean of 18.8 mg/m^3 in the upper lake during September. Average phytoplankton and zooplankton densities reached maximums of just over 18 000 organisms per liter (lower lake - Sept.) and 153 individuals per liter (lower lake - June), respectively. Phytoplankton populations were dominated by diatoms and dinoflagellates, while zooplankton populations were dominated by copepods, opossum shrimp, and various species of rotifers. Large pelagic cladocerans are notably absent from Twin Lakes. The benthos includes chironomid larvae, oligochaetes, and fingernail clams. Maximum densities of each, respectively, during 1981 were 1471, 974, and 1536 per square meter in the lower lake and 822, 2900, and 86 per square meter in the upper lake.

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James F. LaBounty
James J. Sartoris

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Applied Sciences Branch
Division of Research
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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CONTENTS

APPENDIXES

CONTENTS—Continued

TABLES

FIGURES

FIGURES (Continued)

INTRODUCTION

The present ecological studies of Twin Lakes began in 1971. Reports on the results of activities prior to this report are found in references [1-23] and [43][1]. Also, quarterly activity reports dating back to 1976 are available as Applied Sciences Referral Memorandums and filed as internal documents at the Bureau of Reclamation, E&R Center, Denver, Colo. The data presented in this report are primarily from calendar year 1981. The Mt. Elbert Pumped-Storage Powerplant began testing procedures in July, and began operation in September 1981. Since the operation was somewhat sporadic during 1981, effects on the ecology of Twin Lakes are still speculative. The present study is planned to continue through at least 1984. During that time, it is planned that the powerplant's second 100-megawatt unit and the new Twin Lakes Dam will be put into operation. The overall goal of this study is to present a comprehensive and accurate analysis of the effects of operating the powerplant on the aquatic ecology of Twin Lakes.

APPLICATION

Results of this study will be combined with other preoperation data to describe the preoperation physical, chemical, and biological limnology of Twin Lakes for comparison with postoperation conditions to assess the impact of the Mt. Elbert Powerplant. Information from these studies is also being used by planners and designers of the Bureau of Reclamation in preparing designs and plans of other pumped-storage facilities. Those involved in assessing environmental effects of pumped-storage powerplants will find data from these studies useful. Results of these studies will also be of interest to anyone involved in the study of lake ecosystems, especially those systems located in montane regions.

[1] Numbers in brackets refer to entries in the Bibliography.

GENERAL DESCRIPTION

Twin Lakes are located on Lake Creek at the eastern front of the Sawatch Range in the upper Arkansas River Valley of central Colorado (fig. 1). The lakes are 2802 m above mean sea level. The present topography of the western side of the Arkansas River Valley in the Twin Lakes area is largely the result of glacial action on earlier alluvial deposits (Buckles, 1973) [24]. Twin Lakes probably originated with the morainic damming of Lake Creek (Sartoris, et al., 1977) [10]. The shoreline and bottom topography of Twin Lakes are shown on figures 2 and 3, respectively.

Present maximum water surface areas are about 263.4 ha for the upper lake, and 736.5 ha for the lower lake, with corresponding depths of about 28 and 27 m, respectively.The lower lake is the largest natural mountain lake in Colorado (Pennak, 1966) [25]. Sartoris, et al., (1977) [10], summarize the literature reporting results of studies done from 1873 to 1977; LaBounty, et al., (1980) [16] and LaBounty and Sartoris (1981) [21] update this summary. The physical and biological

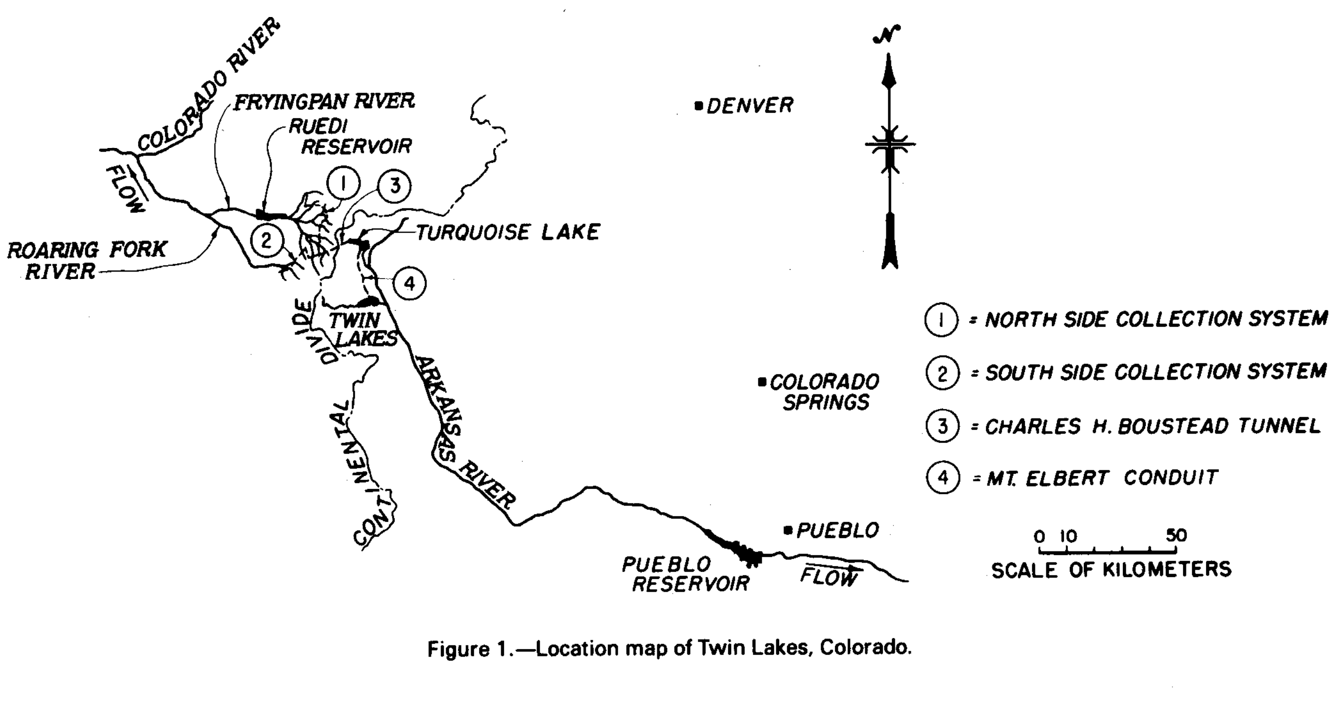


Figure 1.—Location map of Twin Lakes, Colorado.

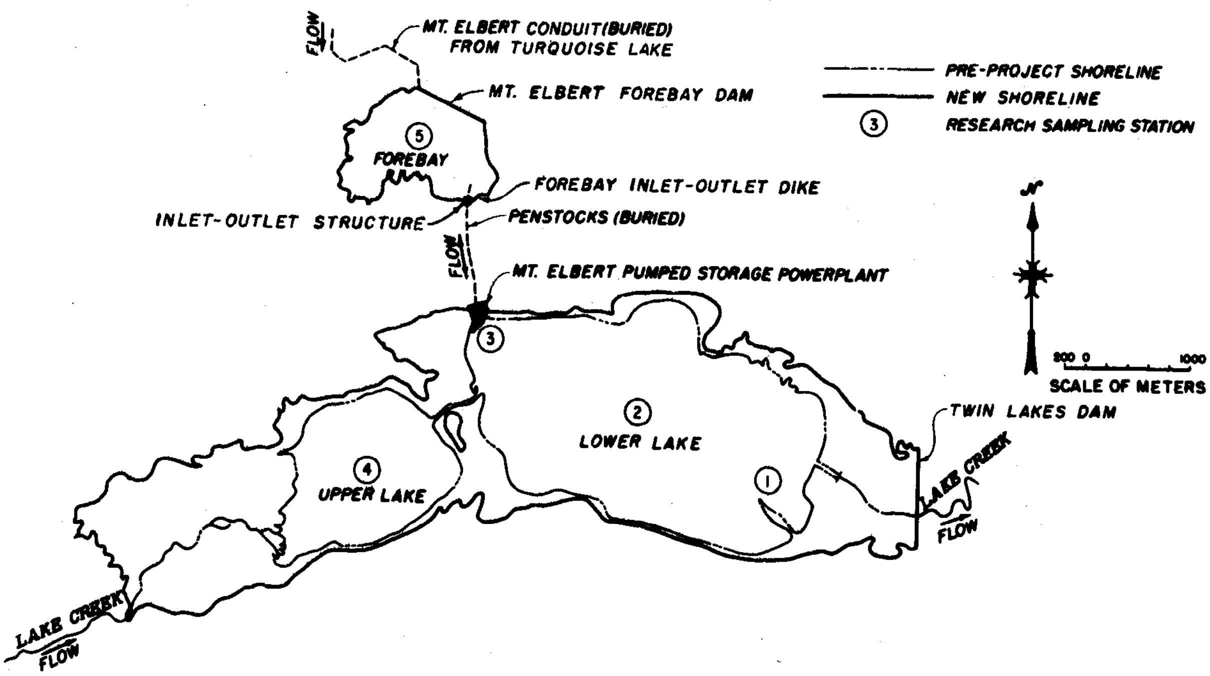


Figure 2.—Twin Lakes shoreline.

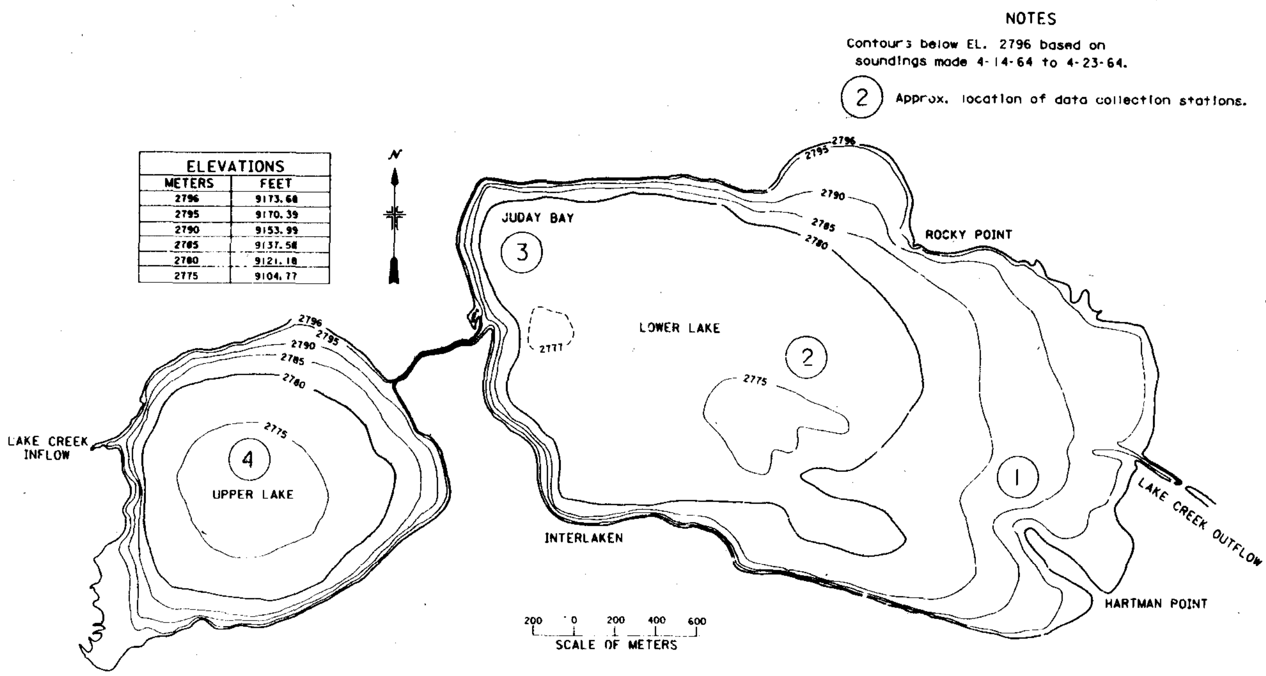


Figure 3.—Bottom topographic map of Twin Lakes.

changes of Twin Lakes during the past 100 years are also discussed in [10].

The installation of the outlet control works, dredging of the channel between the two lakes, human activities in the area, and the introduction of rainbow trout *(Salmo gairdneri)*, lake trout *(Salvelinus namaycush)*, and mysis shrimp *(Mysis relicta)* have altered the original ecology of Twin Lakes since the turn of the century and have interacted to produce the present system. In late 1980, use of the recently constructed Twin Lakes Dam was attempted. In early 1981, use of the dam was terminated pending completion of a number of modifications to control seepage to the dam. Changes in the ecology of the lakes due to inundation of additional land surface are possible when full use of the dam resumes. Further change in the limnology of the lakes is expected to occur when the powerplant operates on a regular basis. Quantification of these impending changes is the main function of this project.

METHODS AND MATERIALS

Table 1 is a summary of the limnological field surveys done during 1981 at Twin Lakes. During each of the surveys, data were collected in the same manner. The following subsections give a brief description of the methods used to collect data for each of the activities listed in table 1. The maps on figures 2 and 3 show some of the general features and the sampling locations referred to in the following text.

Meteorological-Limnological Monitoring

Five specially designed meteorological-limnological instrumentation packages are being used at Twin Lakes. These instruments were designed and constructed by Hydrolab Corporation. Instruments at stations 2 and 4 in the center of the lower and upper lakes, respectively, monitor underwater parameters hourly at two depths. Station 1 instrumentation, located at the east end of the lower lake, monitors underwater parameters at one depth. The instruments on station 3, near the northwest corner of the lower lake, and station 5, in the center of the forebay, monitor underwater parameters at one depth, as well as selected meteorological parameters. Underwater parameters being monitored are temperature, dissolved oxygen, hydrogen ion concentration (pH), and oxidation-reduction potential (redox or ORP). Meteorological parameters include air temperature, average hourly windspeed, and ambient light.

Table 1. — *Field surveys of Twin Lakes during 1981*

Date of survey	Activity performed: Physical factors	Chemical factors	Primary productivity	Chlorophyll	Phytoplankton	Zooplankton	Benthos
Jan. 7-9	x	[1]x	x	x	x	x	x
Feb. 4-6	x	[2]x	x	x	x	x	x
Mar. 2-4	x	[2]x	x	x	x	x	x
Apr. 1-3	x	[2]x	x	x	x	x	x
Apr. 15-17	x	[2]x	x	x	x	x	x
Apr. 28-May 1	x	[1]x	x	x	x	x	x
May 20-22	x	[3]x	x	x	x	x	x
June 1-3	x	[3]x	x	x	x	x	x
June 24-26	x	[3]x	x	x	x	x	x
July 8-10	x	[3]x	x	x	x	x	x
July 22-24	x	[3]x	x	x	x	x	x
Aug. 5-7	x	[1]x	x	x	x	x	x
Aug. 19-21	x	[3]x	x	x	x	x	x
Sept. 2-4	x	[3]x	x	x	x	x	x
Sept. 16-18	x	[3]x	x	x	x	x	x
Sept. 25-26	Stream surveys[1]						
Sept. 30-Oct. 2	x	x	[3]x	x	x	x	x
Oct. 14-16	x	[1]x	x	x	x	x	x
Oct. 28-30	x	[1]x	x	x	x	x	x
Nov. 11-13	x	[3]x	x	x	x	x	x

[1] Complete chemistry, heavy metals, and N-P nutrients.
[2] Heavy metals and N-P nutrients only.
[3] N-P nutrients only.

Underwater Physical-Chemical Factors

Temperature, dissolved oxygen, conductivity, hydrogen ion concentration (pH), and oxidation-reduction potential were measured with a Hydrolab Corporation System 8000 multiparameter probe. Water samples were collected with a Van Dorn water sampler. Grab samples were also periodically collected from the inflow and outflow. Water samples were subjected to the following analyses:

- Major ions
- Trace metals (copper, zinc, iron, manganese, and lead)
- Plant nutrients (orthophosphate phosphorus, total phosphorus, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, and silicon).

Samples for trace metal analysis were preserved immediately after collection with about 1 mL of concentrated nitric acid per 240 mL of water. Samples for nutrient analysis were frozen immediately following collection. All samples were analyzed according to methods given in chapter 5 of the *National Handbook of Recommended Methods for Water Data Acquisition* (USGS, 1977) [26]. Light penetration was measured using both a standard Secchi disk and a limnophotometer. Light extinction coefficients were calculated from the limnophotometer measurements. Light transmittance was measured using a transmissometer which measures the percent of available light passing through a 0.5-m (or other selected length) path of water at any specific depth desired.

Primary Productivity

The net rate of primary production was measured in terms of carbon fixation using radioactive carbon (^{14}C) and following the methods in Wood (1975) [27]. Measurements were always made during peak daylight hours.

Chlorophyll

Samples for chlorophyll analysis were collected from 0.1-, 1-, 3-, 5-, 9-, and 15-m depths in each lake. Following collection, 750-mL samples were filtered through millipore glass filter pads. Chlorophyll extraction and analysis were done according to methods outlined in Parsons and Strickland (1963) [28]. We have revised and adapted this technique to fit our special situation.

Phytoplankton and Zooplankton

Plankton were collected with a closing net having a No. 20 (mesh opening = 0.076 mm) silk net and bucket. Vertical hauls were made from 0 to 5 m, 5 to 10 m, 10 to 15 m, and from 15 m to the lake bottom. Samples were preserved with a 4 percent formalin solution for laboratory analysis. Laboratory methods follow those of Welch (1948) [29].

Benthos

Two or three samples of benthic muds were collected from each station using an Ekman dredge. These samples were screened through a U.S. Standard Series No. 30 sieve size (sieve opening = 0.589 mm) and then preserved in a 10 percent formalin solution for laboratory analysis. All organisms were identified according to type, and then counted and weighed. The dry biomass was obtained by methods from APHA (1971) [30].

RESULTS AND DISCUSSION

Monitoring Equipment

Tables 2 through 6 summarize data collected with the Hydrolab monitoring equipment. Five stations were instrumented; one in the center of the forebay (sta. 5), one in the center of the upper lake (sta. 4), and three in the lower lake (stas. 1, 2, and 3). Data were monitored hourly and stored in the instrument's memory. Stations 1, 2, and 4 have instruments that collect underwater data only: temperature, dissolved oxygen, pH, and oxidation-reduction potential. These data were collected from depths of 1 and 13 m at stations 2 and 4. Stations 3 and 5 have instruments that monitor underwater data at 1-m depths only, plus the following meteorological parameters: air temperature, average hourly wind speed, and ambient light. Since the meterological instruments are prototypes, some problems were encountered resulting in incomplete data from stations 3 and 5.

Tables 2 through 6 also show the monthly averages for some of the parameters monitored at a particular sampling location. Figures 4 through 6 show the temperature and pH values from these tables. Except where indicated, the values displayed are based on 24 hourly readings for each day of the month. It is obvious that this summarization is only a generalization of the conclusions that could be gleaned from the information collected. However, for purposes of this report, the presented averages will suffice. More detail and interpretation will be left for future segment reports. Temperature data in figures 4 through 6 show the warming and cooling trends from May 1 through November 10, 1981. These two temperature trends occur at somewhat even rates, peaking in July. Also, the fact that the upper lake is cooler

Table 2. — *Monthly averages from monitoring instrumentation on lower lake at station 1*

	May	June	July[1]	Aug.	Sept.	Oct.	Nov.[2]
Temperature (°C)	–	–	13.2	14.0	13.3	9.8	6.6
Dissolved oxygen (mg/L)	–	–	7.23	6.90	7.07	7.47	8.53
pH	–	–	7.04	7.26	7.44	7.26	7.45
Redox (mV)	–	–	439	431	411	445	-

[1] July 9-31 only
[2] Nov. 1-10 only

Table 3. — *Monthly averages from monitoring instrumentation on lower lake at station 2*

	May	June	July	Aug.	Sept.	Oct.	Nov.[1]
1-m depth							
Temperature (°C)	7.75	12.98	16.51	16.25	14.02	10.02	6.80
Dissolved oxygen (mg/L)	8.18	7.72	6.73	6.88	7.28	7.56	8.88
pH	7.09	6.74	7.34	7.18	6.92	7.23	7.22
Redox (mV)	–	–	544	583	579	547	551
13-m depth							
Temperature (°C)	7.51	9.80	11.35	10.42	11.44	10.50	7.27
Dissolved oxygen (mg/L)	8.90	7.96	7.03	6.57	6.47	7.67	8.89
pH	6.99	6.80	6.52	6.33	6.46	6.83	6.29
Redox (mV)	561	573	570	579	573	579	594

[1] Nov. 1-10 only

Table 4. — *Monthly averages from monitoring instrumentation on lower lake at station 3*

	May	June[1]	July	Aug.	Sept.	Oct.	Nov.[2]
Water temp. (°C)	6.71	15.10	15.86	15.35	13.34	9.93	6.64
Air temp. (°C)	9.47	–	–	–	10.55	4.40	1.11
Wind (km/h)	9.5	11.3	10.3	12.4	3.9	4.9	2.9
Dissolved oxygen (mg/L)	9.45	7.58	7.41	7.55	7.38	7.54	8.12
pH	7.32	7.58	7.49	7.13	7.33	7.31	7.39

[1] June 18-30 only
[2] Nov. 1-10 only

than the lower lake can be seen in the plotted data. Influence of the thermocline sinking through the 13-m depth during August and September can be seen in the temperature data plotted from that depth. Plotted average pH values may seem to be a collection of scattered values; however, some interesting observations are apparent. Most obvious is the fact that values at 13 m are lower than those at 1 m in both lakes. Values in the lower lake show a low in June, a rise in July when phytoplankton is increasing in abundance, a drop over the next 2 months when primary productivity is depressed, and a rise during October and in early November after turnover occurs and production increases again due to recycling of nutrients. This implied relationship between primary productivity and pH is only a suggestion at this point. However, being oligotrophic lakes (lakes where the water is not well buffered chemically), one might expect such a relationship to prevail. Values at 13 m also relate well with production at that depth. Trends for pH values in the upper lake may not show a good comparison with production because there is the complicating factor of highly sediment-laden inflows during times of runoff. Only after runoff subsides does any significant primary productivity begin in the upper lake. The smooth curve displayed for pH values at 1 m may be because of chemical buffering due to light being cut off by

Table 5. — *Monthly averages from monitoring instrumentation on upper lake at station 4*

	May	June	July	Aug.	Sept.	Oct.	Nov.[1]
1-m depth							
Temp. (°C)	7.28	-	15.13	14.70	12.47	8.95	6.06
Dissolved oxygen (mg/L)	7.42	[2]7.73	7.37	7.20	7.51	7.72	8.53
pH	6.59	[2]7.02	7.31	7.35	7.21	6.80	6.82
Redox (mV)	–	–	–	–	[3]326	[4]389	438
13-m depth							
Temp. (°C)	[5]6.20	7.69	8.97	8.54	8.90	8.72	6.47
Dissolved oxygen (mg/L)	7.88	8.35	7.79	7.25	7.56	7.24	8.30
pH	6.85	6.76	6.71	6.44	6.31	6.75	7.00
Redox (mV)	408	445	397	378	[6]371	360	336

[1] Nov. 1-10 only
[2] Six dates only
[3] Sept. 3-15 only
[4] Oct. 14-31 only
[5] May 1-20 only
[6] Sept. 16-30 only

Table 6. — *Monthly averages from monitoring instrumentation on forebay at station 5*

	Sept.	Oct.	Nov.
Water temperature, 1 m (°C)	13.36	9.03	-
Air temperature (°C)	9.44	2.16	–
Wind (km/h)	14.9	10.3	–
Dissolved oxygen (mg/L)	7.47	8.37	–
pH	6.8	6.2	–

runoff, resulting in lower production (a lower pH in the relatively unbuffered water). Lower values were found in October and early November. This could be from the influence of turnover when the relatively poorer quality hypolimnetic water (in the upper lake only), which may be remnant of runoff (e.g., heavy metal laden), is distributed throughout the water column. Values of pH at 13 m in the upper lake show a similar trend to those from 13 m in the lower lake.

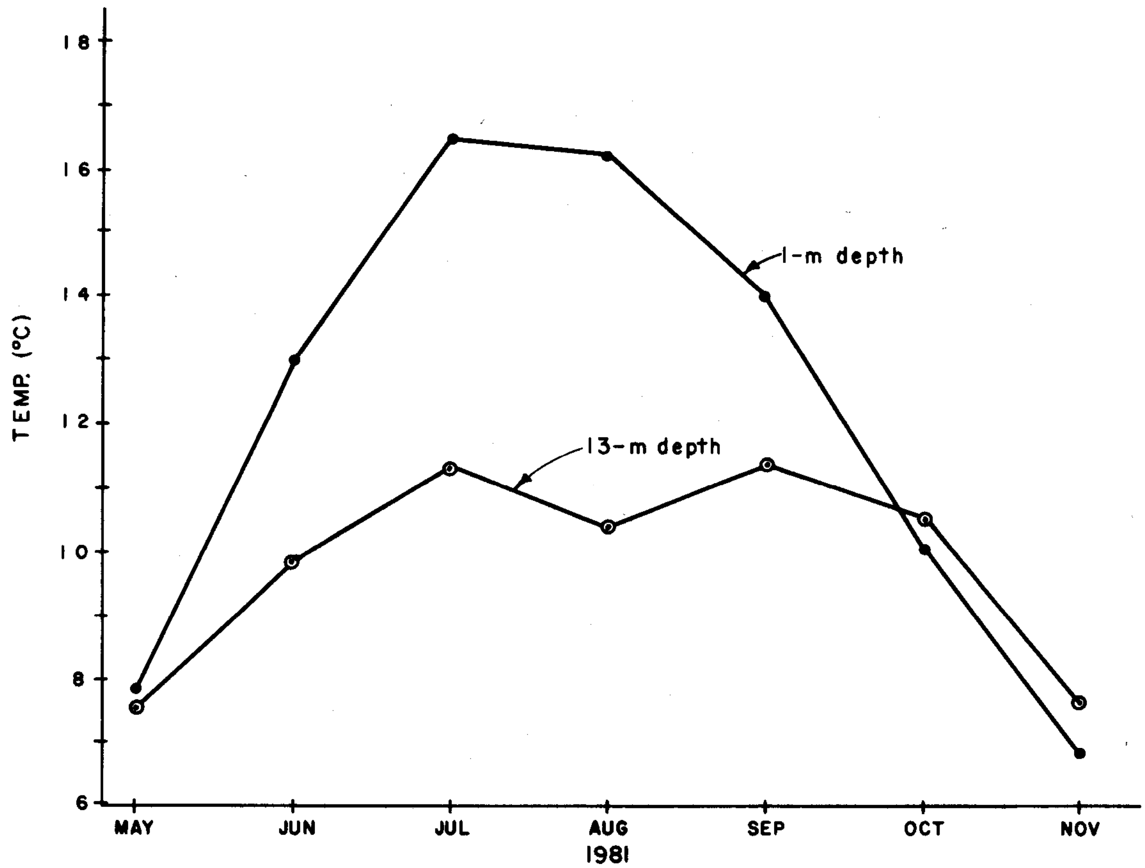
Table 7 presents a summary of four parameters that give a good summarization of Twin Lakes and a comparison of the upper and lower lakes. Both lakes can be characterized by these data as being relatively cool, well oxygenated, poorly buffered, and well into an oxidized state. The average temperature of the upper lake was 1 to 2 °C cooler than the lower lake. Differences in the average temperatures of the thermoclines of the two lakes were greater than those at 1 m because the upper lake receives the Lake Creek runoff.

No differences in dissolved oxygen concentrations within or between lakes seem apparent; however, the percent of saturation calculations reveal that concentrations were, as expected, less at 13 m in both lakes and lowest in the upper lake. Probably the most prominent conclusion from the dissolved oxygen concentration data is that both lakes averaged more than 90 percent saturation in the top 13 m from May 1 to Nov. 10, 1981.

There was little difference in the average pH values between the two lakes either at 1 or 13 m. However, the average pH values were lower in both lakes at 13 m than at 1 m. As previously mentioned, water from Twin Lakes is poorly buffered; thus, at 13 m where biological activity is greatly reduced, the pH values would be expected to be lower, expecially under the thermocline.

The redox values in table 7 show two things: (1) both lakes were well into the oxidizing state, and (2) the values for both depths in the upper lake were, on the average, about 200 mV less than those from the lower lake. This quantitative difference may in fact only reflect a qualitative difference between the two lakes. That is, the upper lake received the sediment-laden runoff

STATION 2



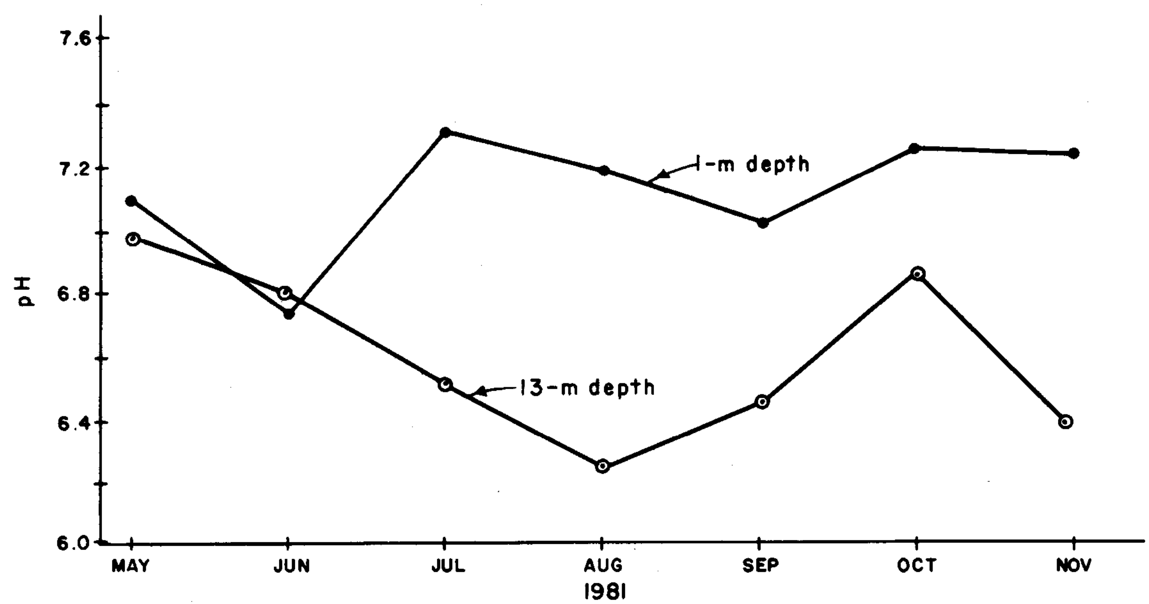


Figure 4.—Average monthly water temperatures and pH values from station 2 in the lower lake monitored at 1- and 13-m depths.

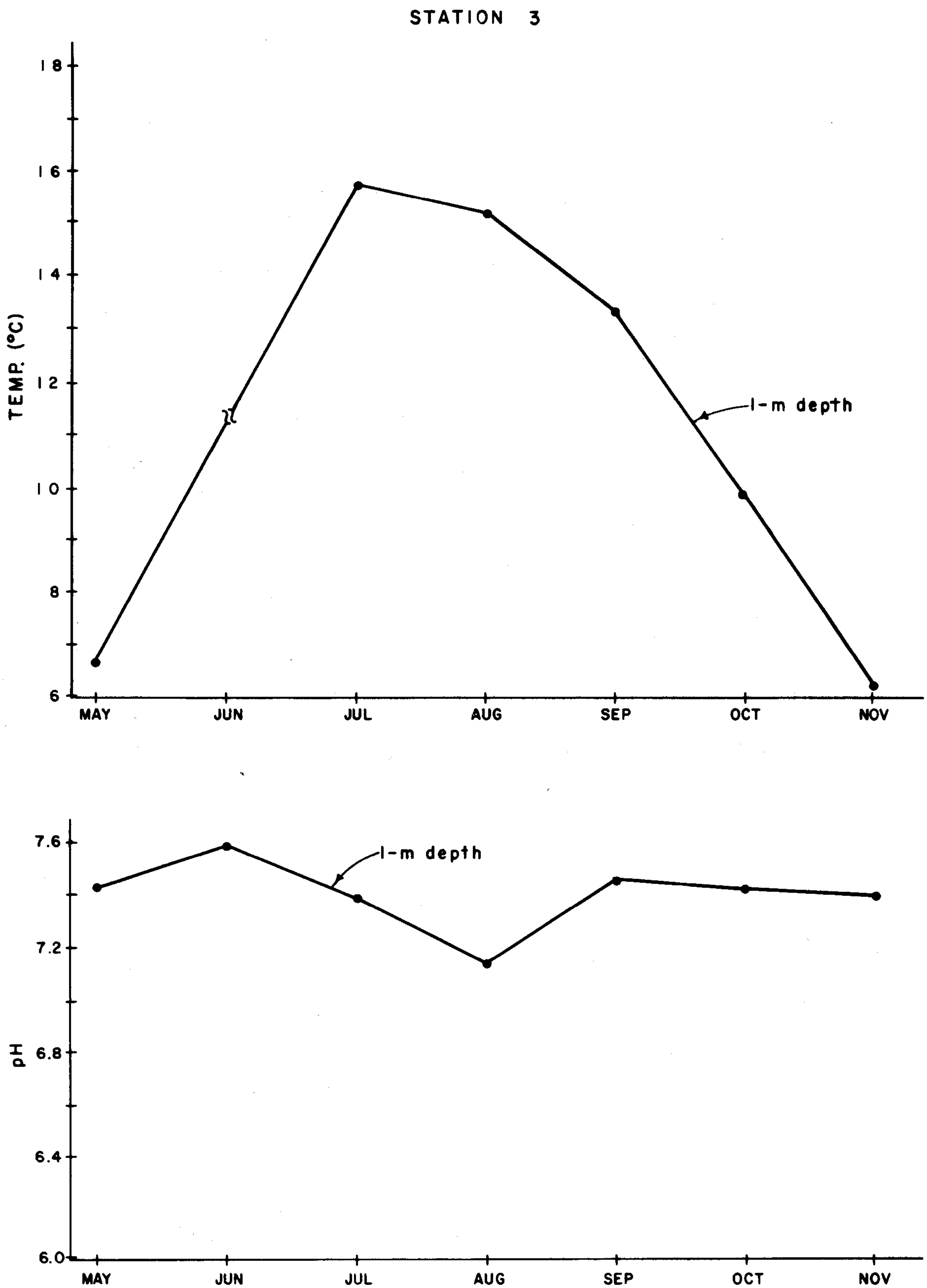


Figure 5.—Average monthly water temperatures and pH values from station 3 in the lower lake monitored at 1-m depth.

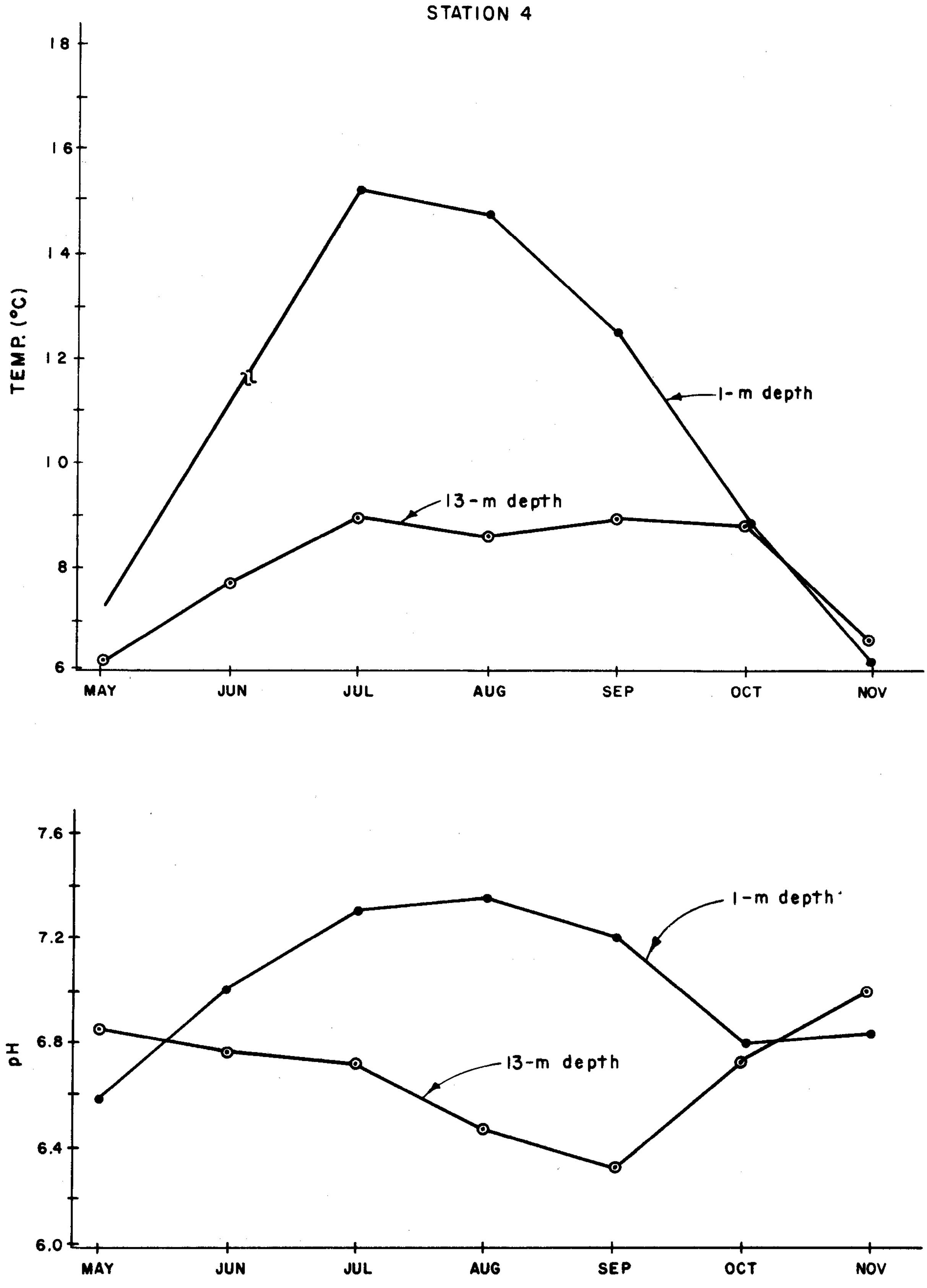


Figure 6.—Average monthly water temperatures and pH values from station 4 in the upper lake monitored at 1- and 13-m depths.

Table 7. — *Average values of four parameters on common dates monitored at Twin Lakes, May 1 through Nov. 10, 1981*

Location and depth	Temp. (°C)	Dissolved oxygen (mg/L)	pH	Redox (mV)
Station 2 (1 m)	12.05	7.60 (100)[1]	7.10	596
Station 4 (1 m)	10.93	7.64 (98)	7.01	390
Station 2 (13m)	9.76	7.64 (94)	6.60	553
Station 4 (13m)	8.09	7.77 (92)	6.69	368

[1] Number in parens is percent of saturation.
Note: 4632 Observations recorded

and the lower lake is more productive biologically. No other conclusions can presently be made from the redox data; however, it should be recognized that these continuous recordings of redox potential provide the best information known to date on oxidation-reduction potentials in open waters.

Inflow-Outflow

Figures 7 and 8 present inflow and outflow volumes for 1981 and for the 10-year period 1971-81. The general observation that 1981 was a drought year is supported by the fact that the inflow to Twin Lakes during the normally peak flow month of June 1981 was only 63 percent of the 1971-81 average. During July 1981, the inflow was only 52 percent of the 10-year average. Total inflow to Twin Lakes during 1981 was 70 percent of the 10-year average. However, inflow during October, November, and December 1981 was substantially greater than normal. This was due to operation of Mt. Elbert Conduit which carries water from Turquoise Reservoir to Mt. Elbert Forebay. Thus, where inflow to Twin Lakes before project operation was primarily by way of Lake Creek, a significant contribution, since September 1981, now comes by way of Mt. Elbert Conduit and Powerplant. Inflows during October, November, and December 1981 were 660, 907, and 1,171 percent of the average flows, respectively, for the same months during 1971-81. This difference in flow regime can be expected from now on. The outflow regime from Twin Lakes is somewhat different than the inflow. Most noticeably, the peak flow month of June found in the inflow data is diminished. This occurs when the lakes are allowed to fill. Similar to inflow volumes, outflows from Twin Lakes were near or below the 10-year average through July 1981. During the last 4 months of 1981, outflows were greater than average, reflecting the increased inflow by way of Mt. Elbert Conduit. Outflows during June and July 1981 were 82 and 84 percent of average, respectively. Outflows during August, September, October, November, and December 1981 were 120, 205, 298, 535, and 1,668 percent of the average, respectively. The October, November, and December outflows were significantly greater than the 10-year average. Outflow for 1981 was 118 percent of normal compared to 70 percent for inflow, indicating a loss of water from storage in Twin Lakes during 1981. Again, these values reflect the change in flow regime brought about by the commencement of operation of Mt. Elbert Conduit and Mt. Elbert Pumped-Storage Powerplant.

Average Water Temperature

Figure 9 presents average monthly water temperatures for all depths during 1981 versus the 7-year averages for both the upper and lower lakes. Both lakes were generally warmer during 1981, probably reflecting the relatively warmer ambient temperatures which occurred that year. Also notable on this figure is the relative lack of smoothness in the annual curve for 1981. The lakes seemed to warm up more quickly in June, go through some uncharacteristic cooling in September, and then reflect a relatively mild period in early October. The peak average temperatures of 10.7 and 12.8 °C for the upper and lower lakes, respectively, occurred in late August. On the average, the peak temperatures occur in August and are 9.8 and 12.1 °C, respectively, for the upper and lower lakes. The lakes were about 1 °C warmer during 1981 than the average for the 7-year period 1974-80. As has generally been true, the upper lake was about 2 °C cooler than the lower lake during the months of May through October. This is because the upper lake receives the cool inflow from Lake Creek. This cool inflow goes to the bottom of the upper lake while the lower lake receives the relatively warmer epilimnetic water from the upper lake. Since the operation of Mt. Elbert Pumped-Storage Powerplant will reverse the flow between the two lakes at times, some change in this generalization can be expected.

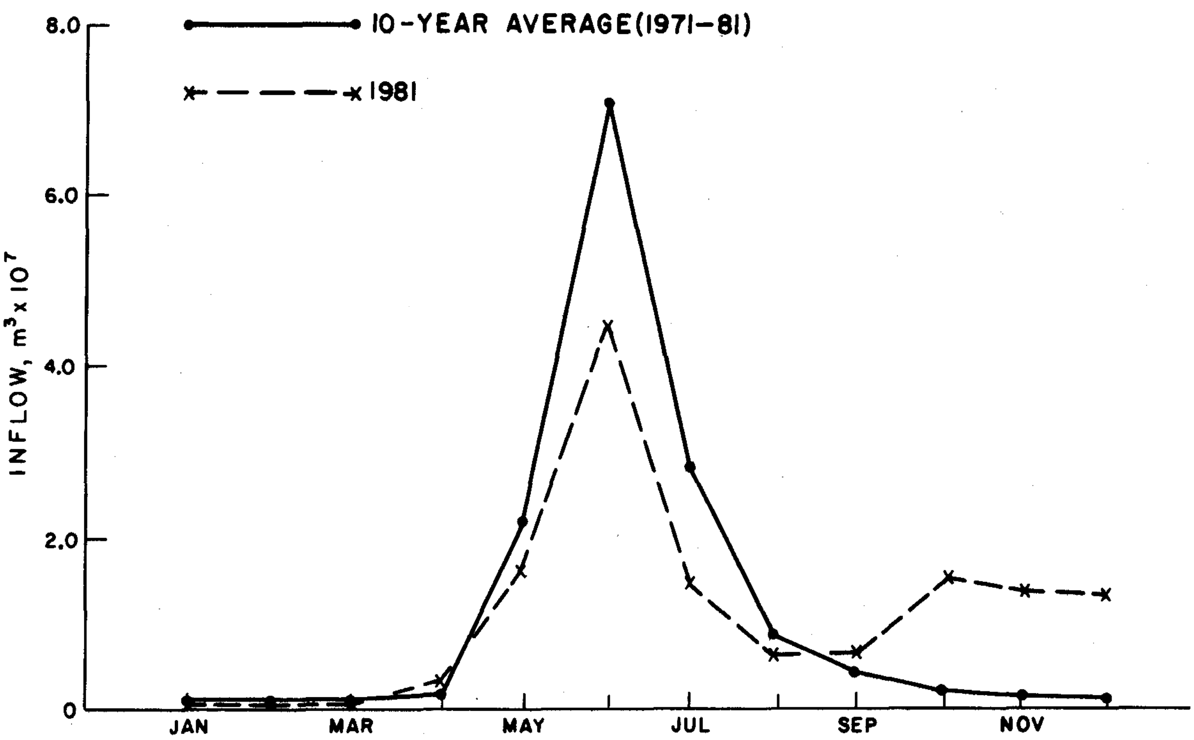


Figure 7.—Inflow volumes to Twin Lakes.

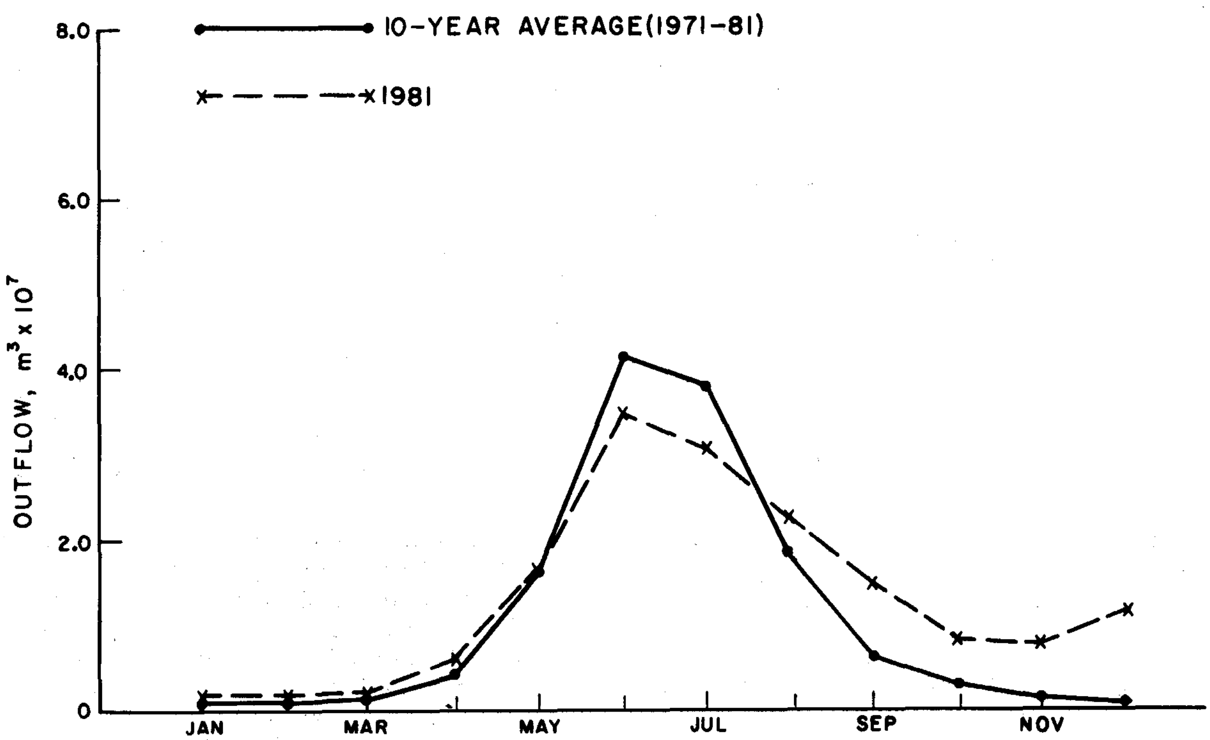


Figure 8.—Outflow volumes from Twin Lakes.

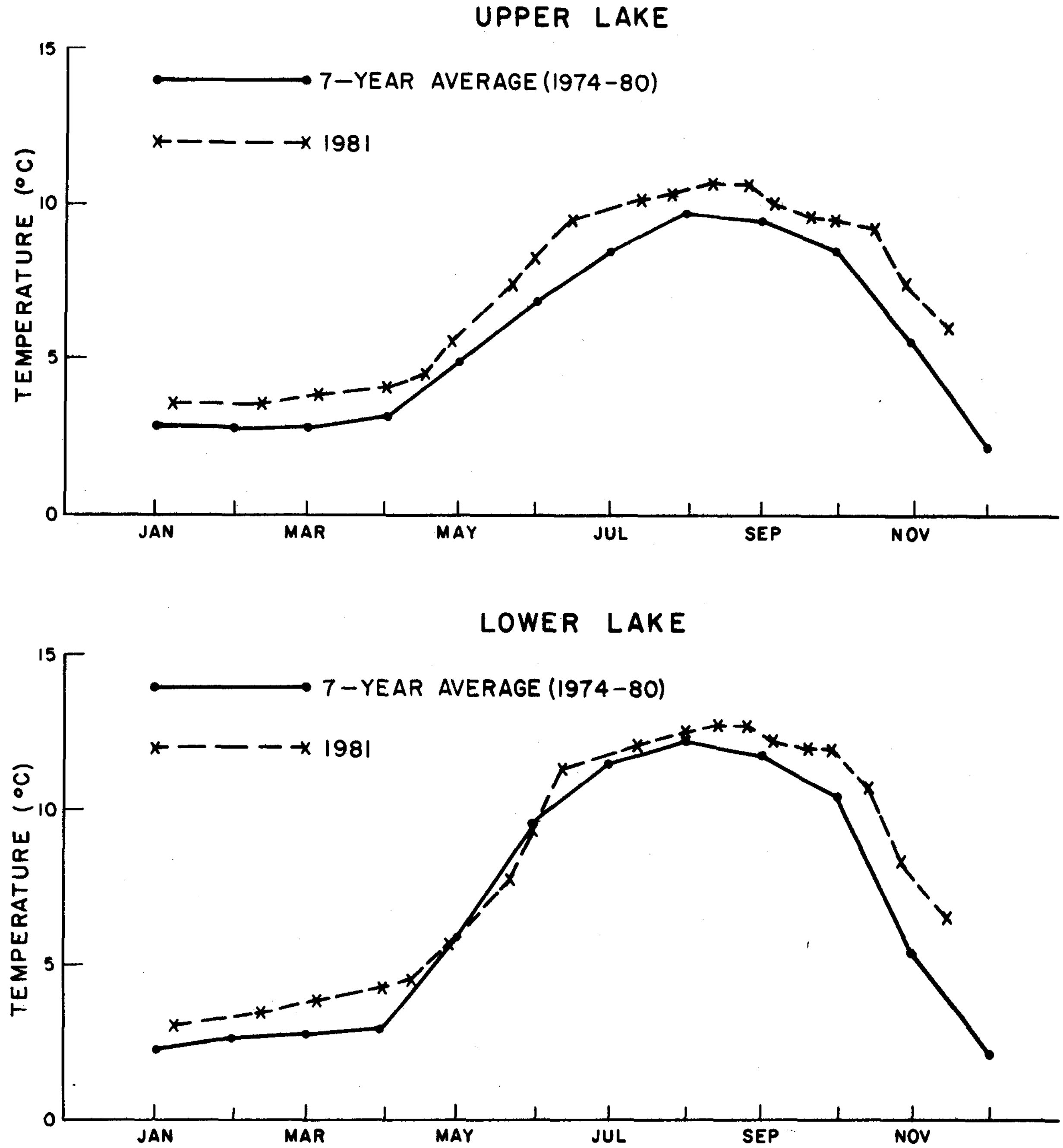


Figure 9.—Average monthly water temperatures for Twin Lakes.

Physical-Chemical Profiles

This subsection presents isopleth drawings of temperature, dissolved oxygen, and pH for the upper and lower lakes. The ice cover and lake bottom are sketched in at the top and bottom respectively, on each of these drawings. The lake bottom line varies in position reflecting changes in lake depth. This is different from most isopleth drawings which indicate the changing water depth in terms of elevation. The lakes were ice-free for 244 days from April 21 to December 23. This compared to 208 ice-free days during 1980, reflecting how relatively warmer 1981 was. The lakes were thermally stratified during this period from about April 30 to October 16, or about 169 days. The lakes were stratified for about 148 days during the ice-free portion of 1980. This means that the lakes were subject to turnover during 1981 for about 10 days in the spring and about 69 days in the fall. While the ice went off later in 1980 than noted during the past 10 years, the ice went off earlier in 1981 than noted since 1971. In addition, the ice went on almost 2 weeks later in 1981 than in 1980, the two latest dates of ice formation on Twin Lakes since at least 1971. December has always been a difficult time for collecting limnological data from Twin Lakes because of inclement weather and unsafe ice. The past 2 years have been especially difficult, and we were unable to do any December sampling. Even though we have concluded that biologically there is not much occurring at Twin Lakes in November and December, this void in our data base continues to be bothersome in light of a most complete data base for all other months.

Temperature. — Temperature data found on figures 10 and 11 show that both lakes were strongly stratified during the 1981 summer with peak stratification occurring during late July and early August. Severe drawdown of the reservoir, as noted by the upswing of the bottom line in early August, disrupted the stratification buildup in both lakes. During the period between mid-July and mid-August, water temperatures in the lower lake remained above 17 °C at depths less than 4 m. Surface water temperatures of at least 16 °C were sustained in the lower lake from early July until mid-August. During that time, the maximum measured water surface temperature was 18.0 °C. The 16 °C water surface temperature of the upper lake was sustained from early July until mid-August. Stratification in both lakes can be described as "classical" from late June through at least September, which usually means that there is a temperature decrease of at least 1 °C per meter of depth separating the epilimnion and hypolimnion. There have been years when a classical thermocline formation in the upper lake did not occur; years when runoff was high, the lakes were low, and/or the summer was colder than normal.

The hypolimnia of the two lakes remained cooler during 1981 because of relatively strong stratification. Bottom temperatures in the lower lake remained below 9.6 °C all year and below 9.0 °C until early September. Bottom temperatures in the upper lake remained below 7.7 °C all year and below 7.0 °C until early September. The severe drawdown which occurred in August probably influenced this pattern by drawing the warm water off the surface of the lakes; thus, reducing the heat available for mixing into the hypolimnion.

As during most years, a large part of the volume in both lakes included water with temperatures at or below 10 °C in 1981. Therefore, since the optimum temperature for lake trout is below 10 °C, the Twin Lakes remain as an excellent lake trout habitat. Fall turnover usually occurs by the second week of October. The lakes were completely mixed by October 16 or 17, which is near normal for this event.

Dissolved Oxygen. — Figures 12 and 13 present dissolved oxygen data from Twin Lakes during 1981. The highest dissolved oxygen concentrations of >10 mg/L occurred in both lakes during the winter under the ice when water temperatures were coldest. Concentrations >8 mg/L were found at 4- to 10-m water depths in the upper lake during July due to photosynthesis by phytoplankton. At the bottoms of both lakes, low readings of from 2- to 4-mg/L of dissolved oxygen concentrations (equal to between 30 and 50 percent saturation) were noted during early April and again in early October. The lowest concentration measured in 1981 was 1.7 mg/L (or about 18 percent saturation) on October 1 at the bottom of the lower lake. Patterns of the concentrations during 1981 resembled those from other years at Twin Lakes. During some years, even lower concentrations than those measured in 1981 have been found near the bottom of both lakes, especially in the upper lake during late winter. However, after 7 years of continuous data collection, dissolved oxygen concentrations at or near 0 mg/L seem to be the exception rather than the rule.

Hydrogen Ion Concentration (pH). — Figures 14 and 15 present pH isopleths for Twin Lakes during 1981. Temporal patterns of pH values in both lakes show the normal reflection of thermal stratification. During winter, the pH ranged from 6.3 to 6.4 near the bottom of the lower lake in late February and March to above 8.0 just under the ice of both lakes during early April. During summer, the pH values ranged from lows of between 6.5 and 6.6 at the bottom of both lakes in early October to between 8.1 and 8.2 in June through August in the lower lake and during late July and early August in the upper lake. The pH of Twin Lakes varies greatly because the water has a relatively low conductance (less than 90 μS/cm) and is thus poorly buffered. Generally, the pH varies because of the amount of biological activity and/or the influence of benthic chemical processes in this poorly buffered water. The biological activity and chemical processes in the benthic environment during stratification periods greatly influences the carbonate-bicarbonate shift. Normally, turnover occurs during spring along with the onset of runoff. Both events cause an increase in dissolved and suspended material in the water column. The lower pH values at this

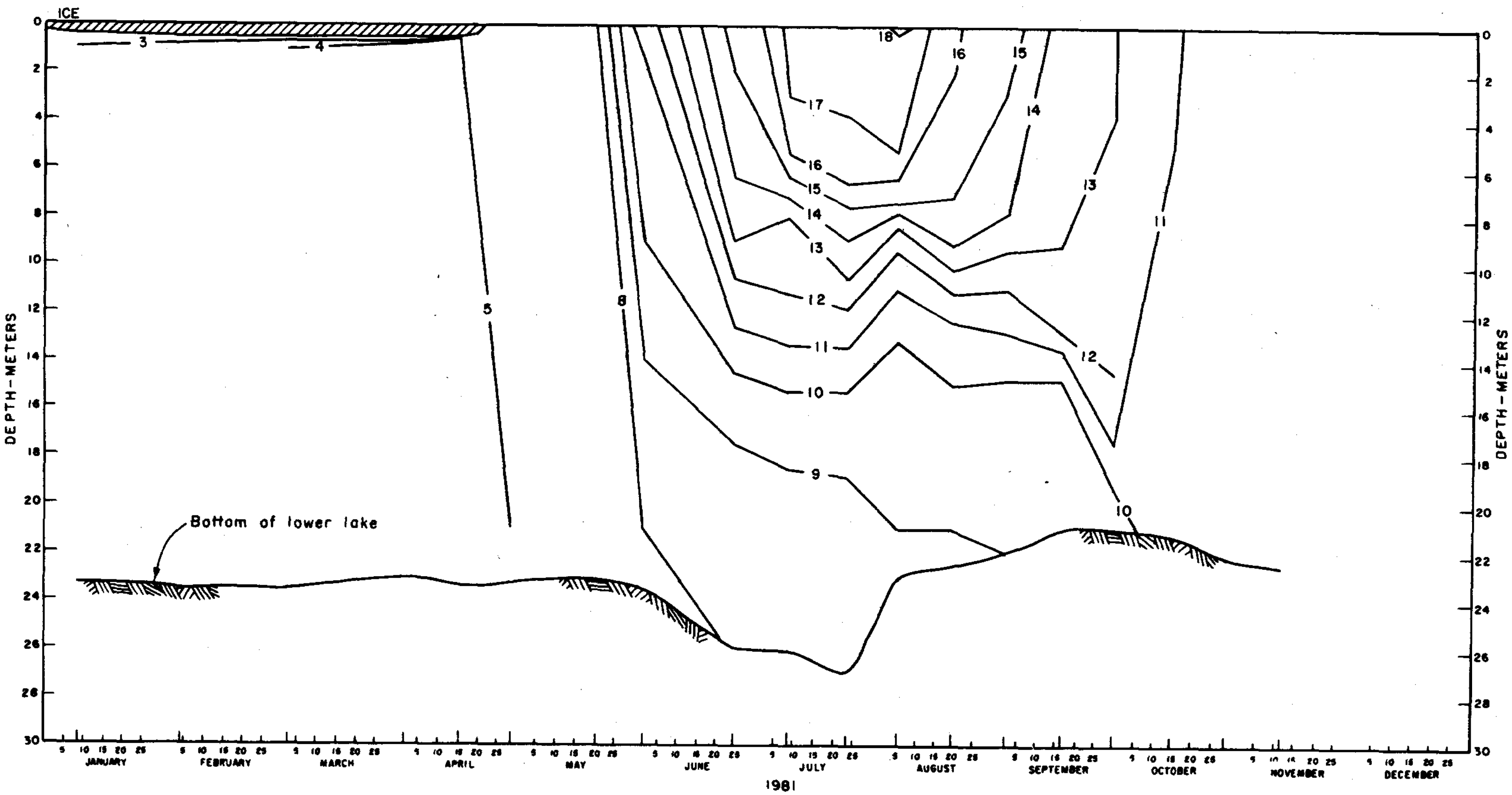


Figure 10.—Temperature isopleths for station 2 in lower lake during 1981.

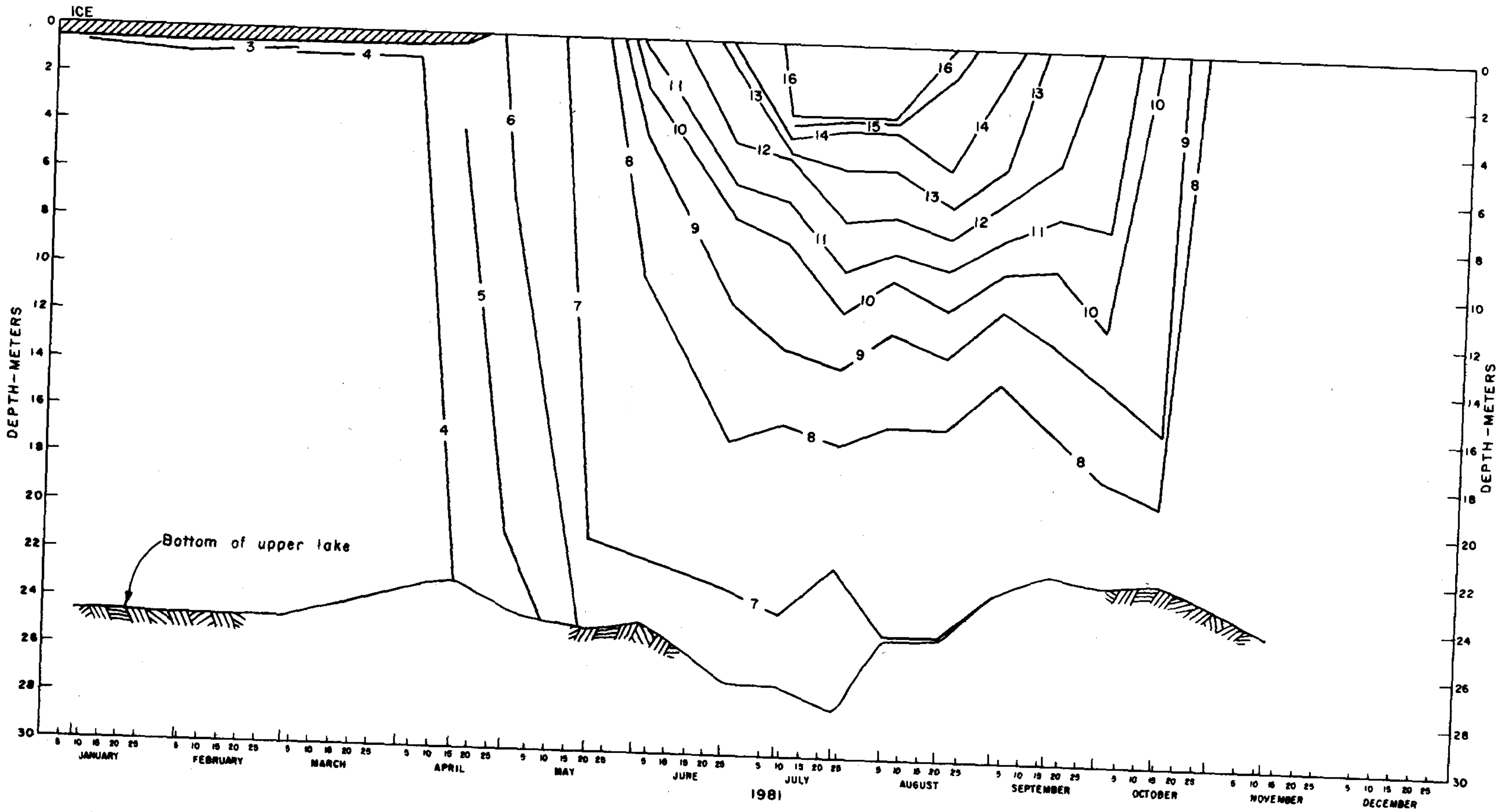


Figure 11.—Temperature isopleths for station 4 in upper lake during 1981.

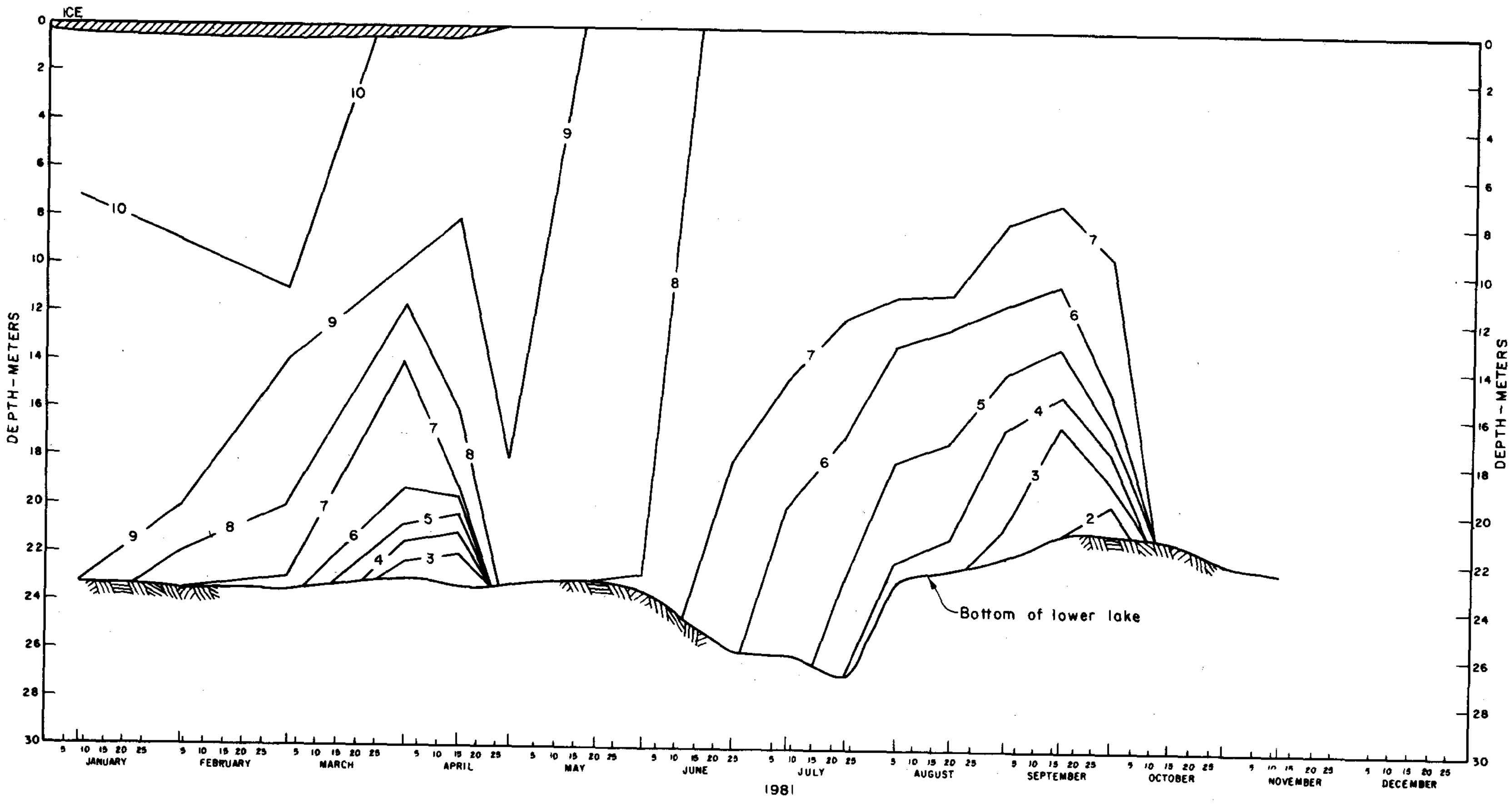


Figure 12.—Dissolved oxygen isopleths for station 2 in lower lake during 1981.

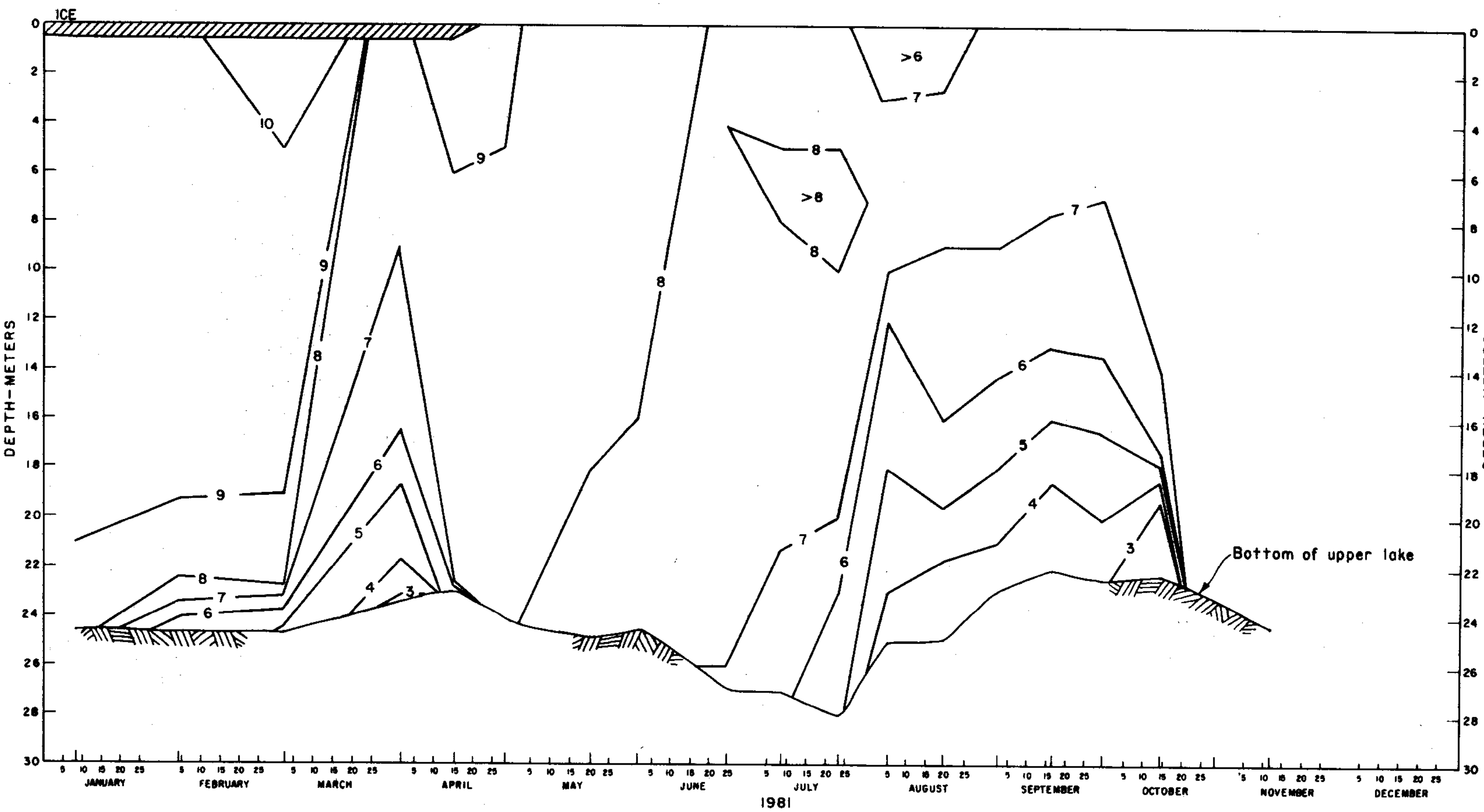


Figure 13.—Dissolved oxygen isopleths for station 4 in upper lake during 1981.

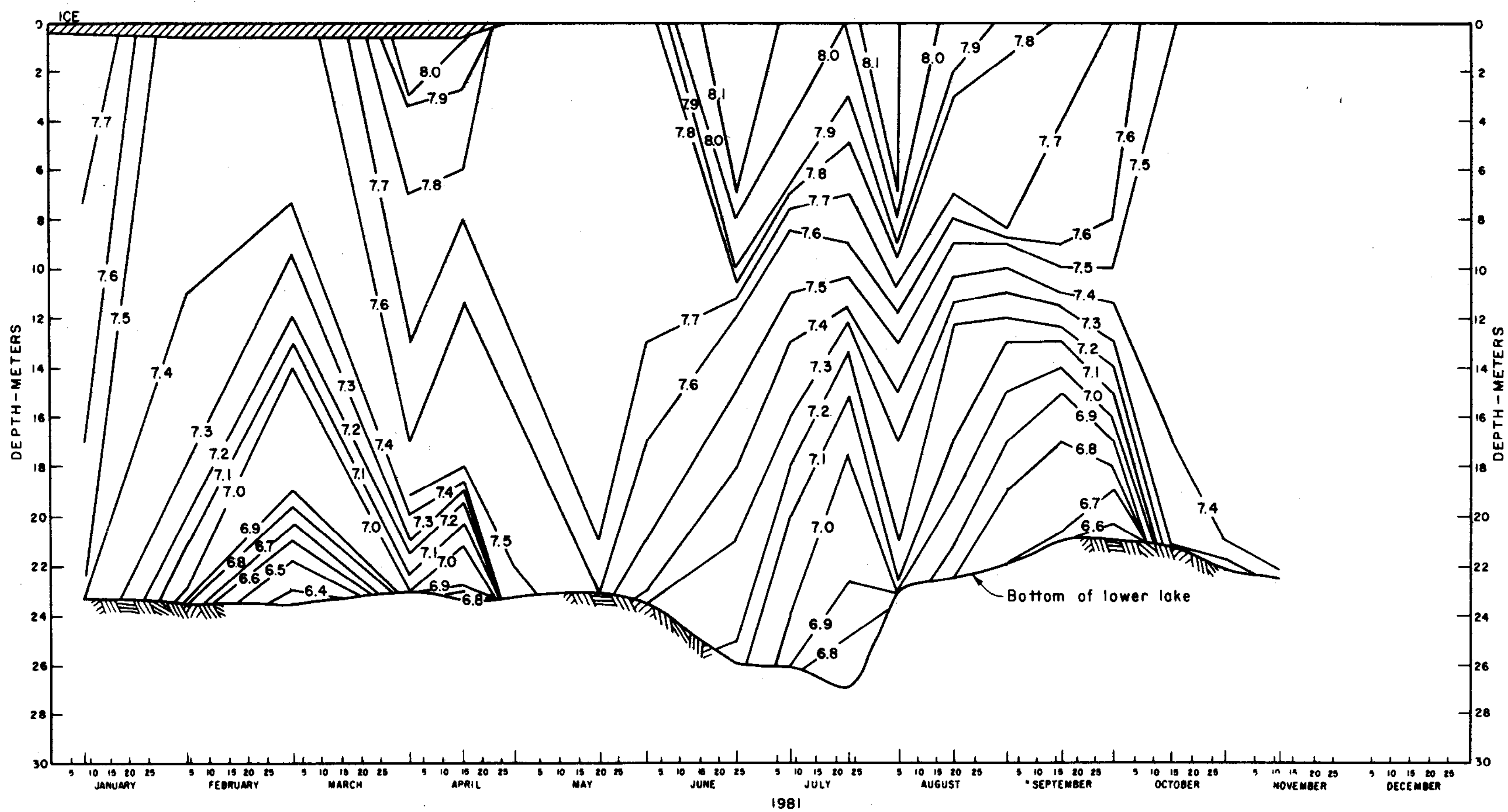


Figure 14.—Hydrogen ion concentration (pH) isopleths for station 2 in lower lake during 1981.

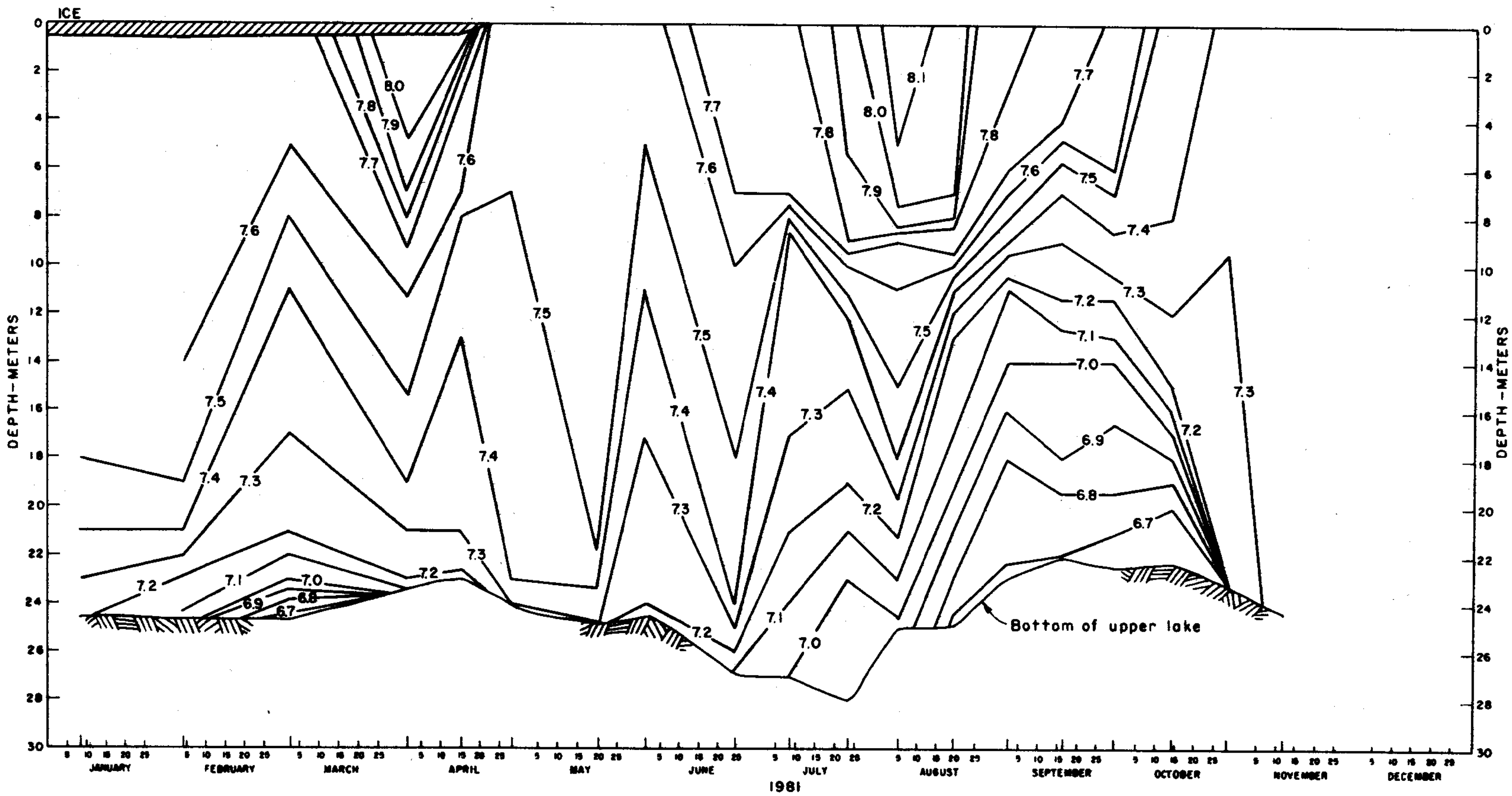


Figure 15.—Hydrogen ion concentration (pH) isopleths for station 4 in upper lake during 1981.

time are leftover from winter stratification. Generally, low pH values of the bottom coincides with the thermal stratification. As soon as runoff subsides, the lakes stratify, biological activity increases, and the pH values increase. This applies to the epilimnion. During some years, pH values in the water column, above the lowest part of the hypolimnion which is influenced by bottom chemical processes, can range from 7.2 to 8.4. During 1981, this range was only about 7.5 to 8.2.

Conductivity. — Figure 16 presents the average conductivity data for Twin Lakes in 1981. Plotted values were averaged from surface to bottom for each sampling date. Average conductivity ranged from 69 to 102 μS/cm for the upper lake and 73 to 92 μS/cm for the lower lake. Data on figure 16 reflect the influence of runoff, especially in the upper lake. Also notable is the effect of water with relatively lower conductivity that arrives from Turquoise Reservoir through the Mt. Elbert Conduit and Powerplant. Flows through the conduit began September 1, 1981, as indicated on figure 16 by the large drop in average conductivity. This change in the flow regime caused a change in the normal pattern of conductivity versus time. Normally after runoff ends, conductivity increases and peaks out in late winter or early spring. This new flow regime will continue to change some normal patterns in Twin Lakes.

The average conductivity values were 87 and 81 μS/cm for the upper and lower lakes, respectively. These values are about 10 percent higher than the average conductivity for the lakes during 1980, reflecting the below average snowmelt runoff in 1981. However, this difference is not statistically significant.

Oxidation-Reduction Potential. — Figure 17 presents the redox potential values measured at the bottom of Twin Lakes during each of the 19 surveys in 1981. Since this is more a qualitative measure than quantitative, values were grouped. Values ranged between 266 and 439 mV in the upper lake and between 296 and 465 mV in the lower lake. These values were all somewhat lower than those of past years. However, there is little or no meaning to this difference. The lakes remained well in the range of an oxidizing state during the entire year.

Light Extinction Coefficients

Figure 18 shows the light extinction coefficients for 1981 and the average coefficients for 1974-80. The value of the light extinction coefficient is inversely proportional to the water clarity. Therefore, lower values mean higher clarity while higher values reflect greater turbidity or less clarity. As with the inflow data, the pattern for the two lakes was typical during 1981. However, the light extinction coefficient values were much reduced during most of 1981, expecially from April through July. This means the water clarity was greater during this period than during other years. This is a direct result of the below average inflow in 1981. Inflow brings in not only sediment but also nutrients for algal growth, both of which reduce water clarity. The clarity of Twin Lakes is directly related to the volume of runoff.

Data on figure 18 also show another common generalization about Twin Lakes; that is, the clarity of the upper lake is much less than that of the lower lake. The upper lake acts as a settling basin for the inflow of Lake Creek. During years zooplankton of greater runoff, this effect is more pronounced. The ultimate effect of this normal or above-normal runoff to the upper lake is twofold. First, the lake remains turbid and second, the lake is greatly flushed. Both these factors lead to the upper lake being relatively less productive biologically. During years of below normal runoff, such as 1981, the upper lake is more biologically productive, especially during May through August.

Transmissivity

Figure 19 includes profiles of light transmittance for the upper and lower lakes for 15 sampling dates during the year. Year-round transmissivity measurements were available for the first time in 1981. Transmissivity is a measure of water clarity at a given depth, and is expressed as a percentage of transmitted light received by a photocell at the opposite end of a 0.5-m horizontal frame from a standard light source. Analysis of data on this figure reveal many significant qualities of the lakes at the time of the survey. Many of these events are explained in the following paragraphs.

Several factors can cause percent transmittance to decrease including allochthonous sediment, zooplankton, phytoplankton, and resuspended material from bottom sediments. The thermocline, when present, is depicted as the shaded area on figure 19. During the winter and with ice cover (January 7-April 1), both lakes show decreased transmittance near the bottom, indicating the buildup of resuspended material from bottom sediments. A review of the isopleth plots for pH and dissolved oxygen shown in figures 12 through 15, shows how stratification causes depletion of dissolved oxygen and lowering of pH. In addition, specific conductance is 10 to 20 percent greater in this area near the bottom. As a typical example

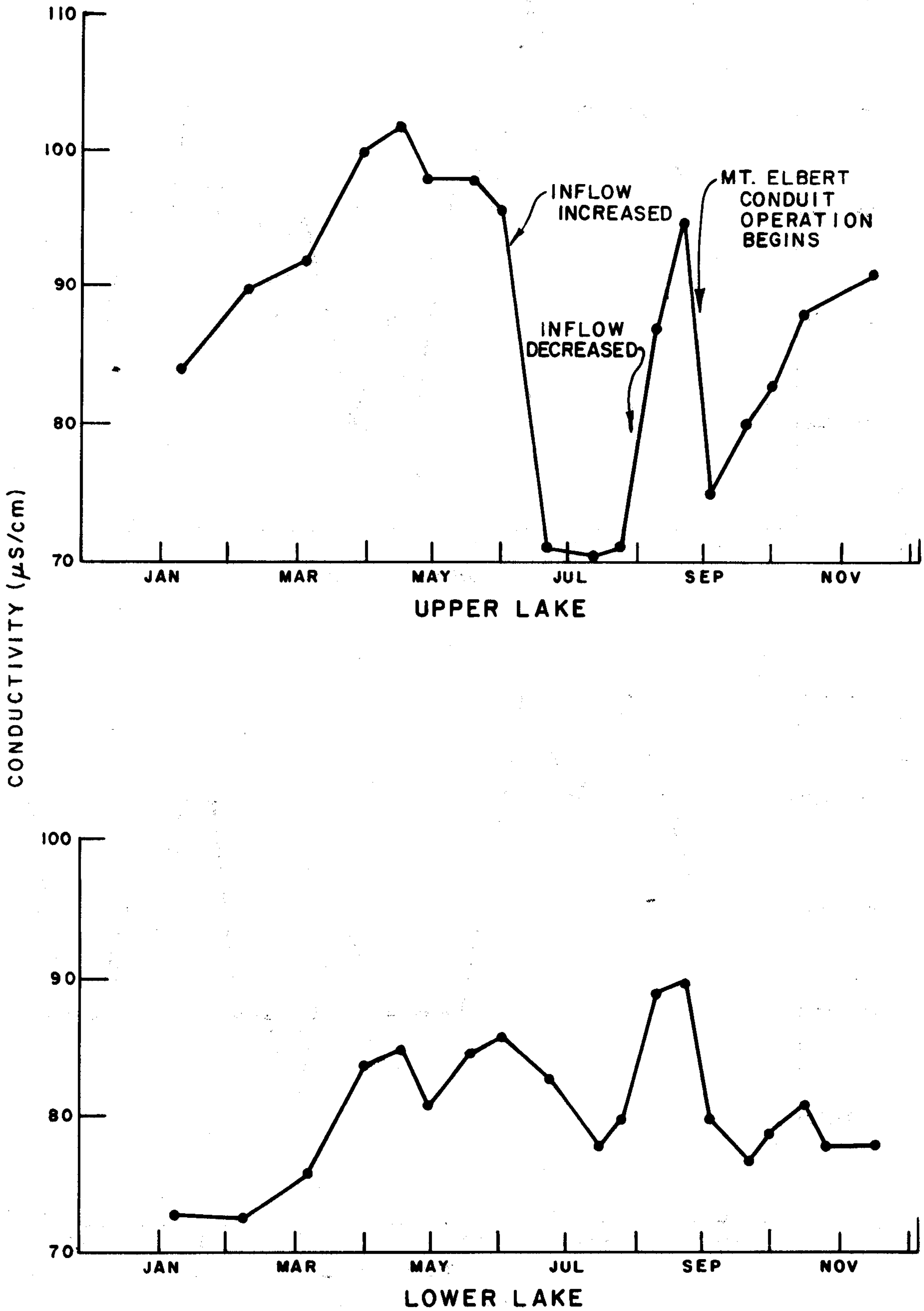


Figure 16.—Average conductivity data from Twin Lakes during 1981.

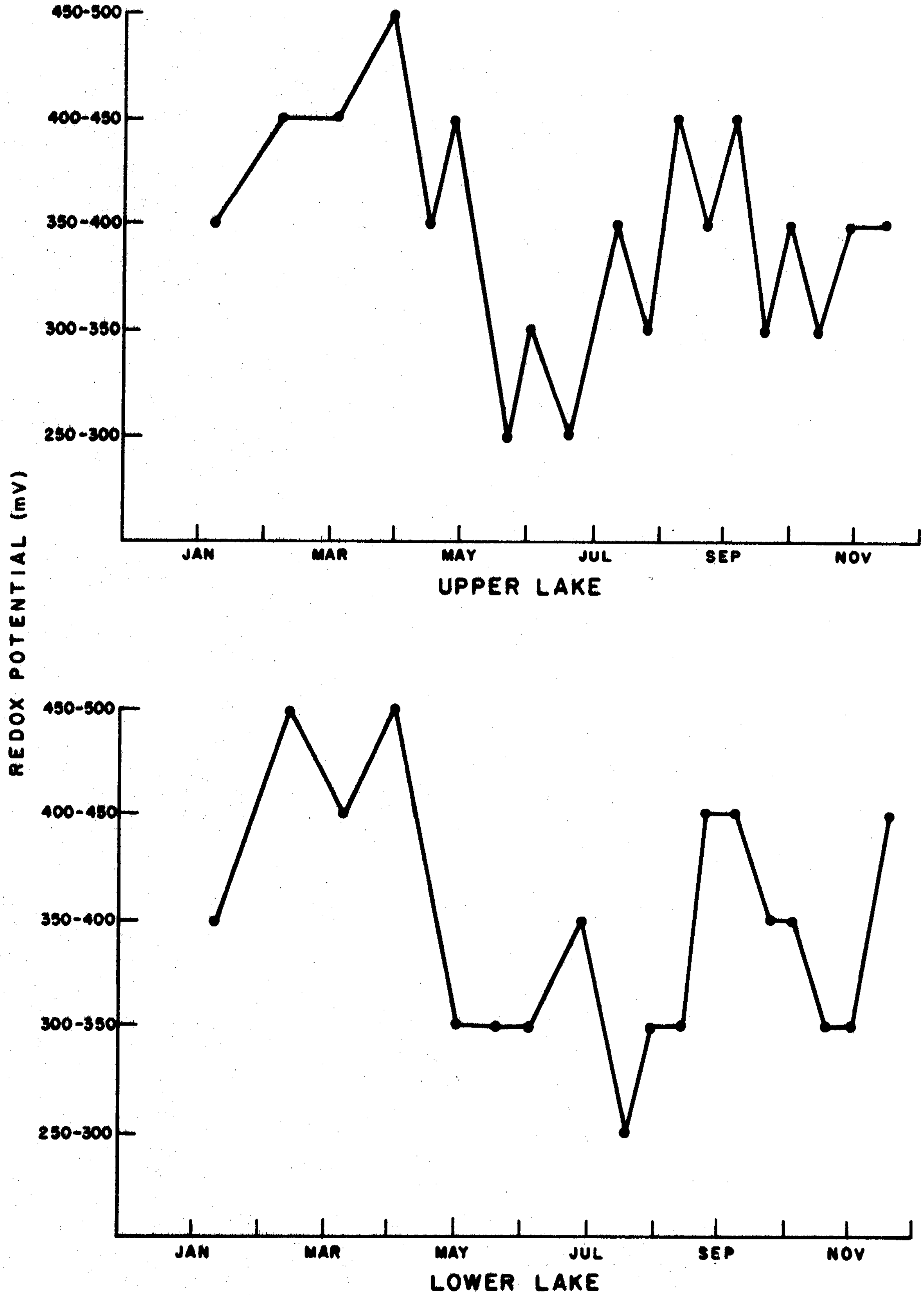


Figure 17.—Bottom oxidation-reduction potential of Twin Lakes during 1981.

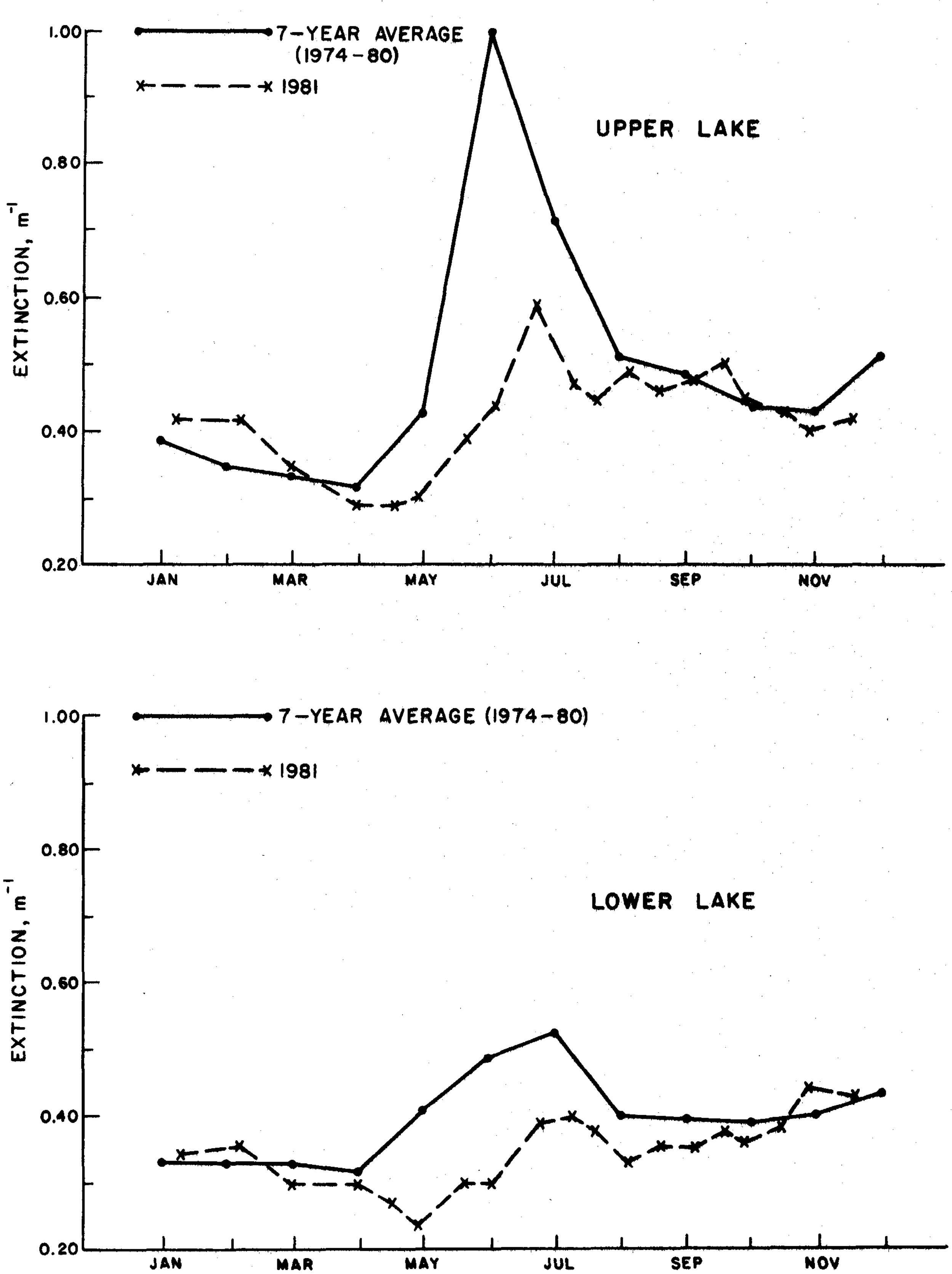


Figure 18.—Light extinction coefficients for Twin Lakes.

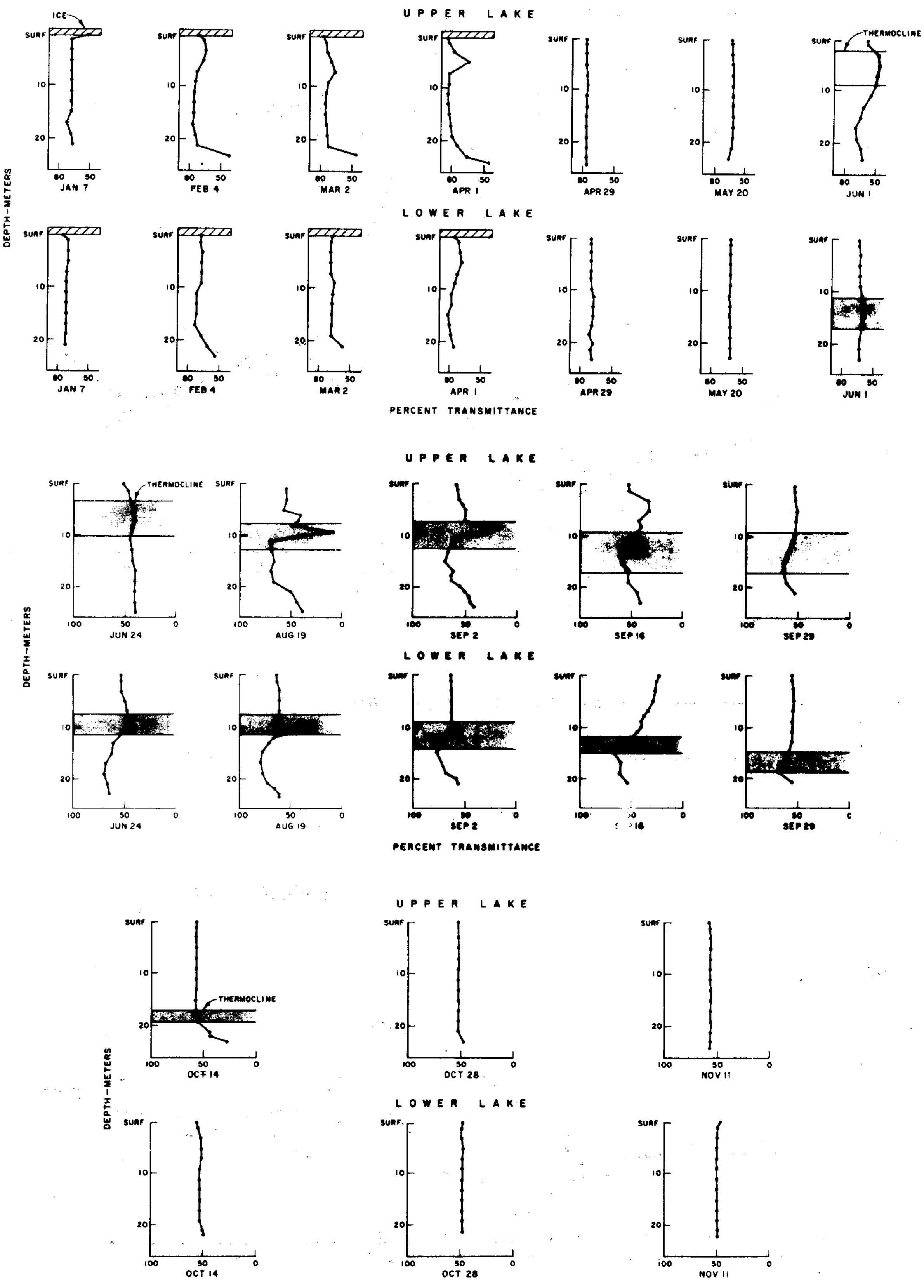


Figure 19.—Light transmittance profiles for Twin Lakes during 1981.

on March 2 in the upper lake, specific conductance just under the ice was 85 $\mu S/cm$, and 97 $\mu S/cm$ just above the bottom. The transmissivity data obviously adds much to the interpretation of this increase in conductivity. Also, during the winter, there is at times a decrease in transmittance just above 10 m in depth. This is especially obvious in the upper lake. No sound evidence exists to explain this. However, in the upper lake, this blip seemed to develop and sink slightly from January through the first of April. This may have been a result of either a turbid inflow or a phytoplankton bloom under the ice. We have no evidence from the data to support either thought.

During months when turnover is occurring (April and May), the transmittance readings were isometrical. The only observation was that on both April 29 and May 20 the lower lake was more turbid than the upper lake. These dates are prior to the time that runoff begins to have its influence on the clarity of the upper lake. Thus, the difference in clarity between the two lakes at this time may be due to wind mixing of the bottom sediment of the lower lake. The lower lake has relatively large shallow areas compared to the upper lake which is more like a bowl. In addition, there is significantly more biota (zooplankton and phytoplankton) in the lower lake than there is in the upper lake.

The profiles from June 1 through September 29 also presented some significance. First and perhaps most significantly, within the thermocline, a phytoplankton bloom developed in both lakes beginning in early June and became well developed by mid-August. By mid-September, these algae had either died or been dispersed. Just above the thermocline (see Aug. 19 profile), accumulated. Below the thermocline, densities of plankton were generally less, resulting in clearer water. Examination of plankton samples collected during this same period substantiate these observations. The dominant species of algae in the area of low transmittance within the thermocline were *Synedra* (lower lake) and *Dinobryon* (upper lake). Furthermore, during the August 19 survey and based on other data collected at the same time as transmissivity readings, it was noted that the dense phytoplankton layer was less than 0.25 m thick. On September 2, this layer was about 0.5 m thick, and on September 16, the thermocline was relatively devoid of large densities of algae. Algae that were still alive on September 16 were dispersed more evenly from the surface to the 10-m epilimnion area of the upper lake. It should also be noted that when the thermocline sank below the euphotic zone, transmissivity within this zone increased. Data from the lower lake show a similar but far less dramatic trend.

The second observation from data on figure 19 showed that from June 1 through September 29, a decrease in percent transmittance occurred 4 to 5 m from the bottom. This decrese is due to either turbulence at the bottom from the diving of colder inflow water, the resuspension of material from bottom sediments, and/or the accumulation of sinking debris from the upper water column. When turnover occurs each year (about October 13-15 in 1981), the nutrients that accumulate in this bottom area are dispersed throughout the water column and are primarily responsible for the normal increase in primary productivity observed during October and November.

The final three profiles (October 14, 28, and November 11) reflect isothermal conditions following fall turnover, with the exception of the upper lake on October 14. These profiles resemble those from the spring except that transmittance was 10 to 25 percent less during the fall turnover period. This is probably due to two factors. First, there is substantially more plankton and organic debris in both lakes during the fall than in spring. Second, either the runoff may be bringing different material in during the fall that include nutrients or there may be stronger circulation of the bottom due to stronger circulation of winds in the fall.

Figure 20 is a plot of the average percent transmittance for each of the 15 dates sampled in 1981. The general trend is apparent in the data displayed on this figure. That is, average transmittance increases under the ice as winter progresses, is lowest in the upper lake when runoff is greatest, rises a little after runoff slows down, drops off somewhat in the summer as biological production along with stratification increases but may decrease again at fall turnover time, and finally begins to increase as winter begins. Whether these generalizations hold true for both lakes during all years remains to be determined with more complete years of transmissivity measurements.

In summary, transmissivity readings in Twin Lakes provide a new dimension into the insight of limnological events occurring in the lakes, and of the spatial and temporal evaluation of these events. The data on transmissivity presented in this report compare favorably with the limited transmissivity data reported for 1973 and 1975 by Sartoris, et al., (1977) [10]. That is, that the transmissivity of Twin Lakes is commonly between 50 and 80 percent.

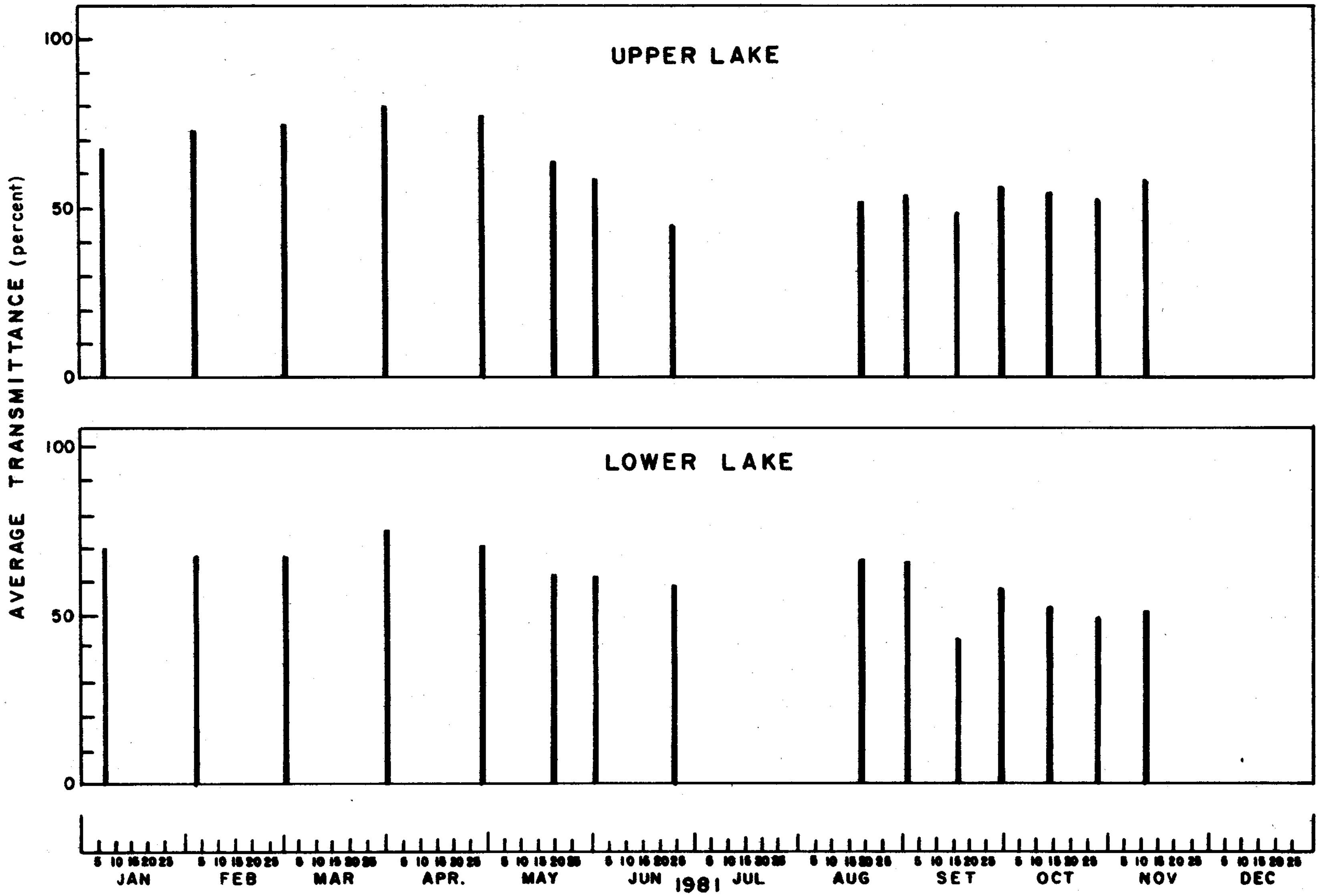


Figure 20.—Average percent light transmittance at Twin Lakes during 1981.

Water Chemistry

Table 8 includes the 1981 maximum and minimum water chemistry data for the Lake Creek inflow and outflow, the upper and lower lakes, and the Mt. Elbert Forebay. Sartoris, et al., (1977) [10], discuss in detail the water chemistry of Twin Lakes for 1971-76. LaBounty, et al., (1980) [16] and LaBounty and Sartoris, (1981) [21], present detailed discussions of water analysis of Twin Lakes water collected during 1979 and 1980, respectively. The points made in these reports also apply to data collected in 1981. That is, in general, water in Twin Lakes resembles other Colorado montane lakes in that the water is extremely soft and characterized as calcium bicarbonate and/or calcium sulfate water with extremely low phosphorus concentrations. The amount of TDS (total dissolved solids) is influenced by the volume of runoff, the greater the inflow, the less the TDS. Also, TDS decreases going downstream. For example, the maximum TDS values in table 8 are 72, 66, 63, and 59 mg/L for Lake Creek inflow, upper lake, lower lake, and Lake Creek outflow, respectively. Since water entering Twin Lakes from Turquoise Reservoir by way of Mt. Elbert Conduit and Forebay is lower in TDS, the Twin Lakes average may be even lower in future years.

Analyses were done for the following heavy metals in water collected in and around Twin Lakes: zinc, copper, iron, manganese, lead, and cadmium. Table 8 lists maximum and minimum concentrations of these metals during 1981. Sartoris, et al., (1977) [10], LaBounty, et al., (1980) [16], and LaBounty and Sartoris, (1981) [21] present detailed discussions of the annual cycle of these metals. Generally, the inflow from Lake Creek provides large concentrations of metals. However, maximum concentrations are usually found near the bottom of each lake during later winter due to benthic processes (biological and chemical). The origin of most of these metals is the South Fork of Lake Creek (Sartoris, et al., 1977) [10]. Twin Lakes are located in the mineralized belt that runs through Colorado. As far as can be determined, the metals come from natural sources found above 3600 m mean sea level. Human influence such as road building, stream improvement[2], mining activities, and forest harvests have also had some impact by increasing the rate of erosion in the watershed. Metals enter the lakes in both the particulate and dissolved forms. The metals then settle to the bottom, principally in the upper lake, resulting in a large buildup of metals in the sediments of the lakes. Results of analysis for metals at various depths within the sediments of Twin Lakes are presented by Bergersen (1976) [6]. When stratification occurs, oxygen in the hypolimnion of either lake is depleted to various degrees, depending on the year. When this condition becomes severe (e.g., dissolved oxygen = 0; pH <7.0), metals are released in their ionic forms which are then toxic to aquatic life in relatively low concentrations, especially the benthos. This phenomenon occurred during during late winter in 1975, and the plankton were so significantly affected it took almost 3 years for full recovery to occur. This severe situation has not been duplicated since. However, the presence of these large quantities of metals in the sediments along with the relatively low TDS means that the potential for another major release is always present. The result would be damaging to much of the aquatic biota of Twin Lakes.

Figures 21 through 25 are plots of the nitrogen and phosphorus nutrient data collected from Twin Lakes during 1981. The arrangement of data on the graphs is from upstream to downstream, top to bottom, and chronological, January through December, from left to right. The TKN (total Kjeldahl nitrogen) concentrations (fig. 21) were greatest throughout the system from early to midyear. Average concentrations for the lakes during 1981 were about 200 μg/L compared to almost half that for 1979 and 1980 (LaBounty and Sartoris, 1981 [21]). Concentrations of nitrate nitrogen show a different pattern (fig. 22) in that the concentrations were relatively low (<10 μg/L) until late June when they were found mostly in detectable concentrations throughout the system. As during other years, concentrations in the inflow were highest, progressively decreasing downstream. There was a net retention of nitrate nitrogen in the lakes, as the export is always significantly lower than the import. The ammonia nitrogen component of organic nitrogen was insignificantly more abundant earlier in the year, and was least abundant in the outflow. Most of the ammonia nitrogen (fig. 23) is generated by heterotrophic bacteria at the sediment-water interface as the primary product of decomposition of organic matter. Since many life cycles of aquatic biota in Twin Lakes are complete in late spring, the higher levels of ammonia nitrogen would be expected at this time. Data from the other years also display this fact.

Figures 24 and 25 contain data on the orthophosphate phosphorus and total phosphorus concentrations of water samples collected from Twin Lakes during 1981. Phosphorus continues to be

[2] Defined here as activities done to improve the stream for transporting water, such as blasting out waterfalls.

Table 8. — *Water chemistry of Twin Lakes during 1981*

Element	Lake Creek inflow		Twin Lakes: Upper Lake		Twin Lakes: Lower Lake		Lake Creek outflow		Mt. Elbert Forebay	
	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
	(mg/L)									
TDS	72.0	42.0	66.0	30.0	63.0	32.0	59.0	33.0	57.0	22.0
Calcium	15.4	7.6	10.4	8.0	10.4	12.0	9.4	9.6	6.2	6.2
Magnesium	1.71	1.46	2.07	0.98	0.98	1.10	1.95	1.59	1.46	1.22
Sodium	1.15	1.15	0.92	0.92	1.15	1.15	1.15	1.38	0.92	1.15
Potassium	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Carbonate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bicarbonate	27.5	21.3	24.4	20.7	22.6	24.4	24.4	24.4	18.3	17.7
Sulfate	25.9	8.16	17.3	8.6	14.9	16.8	13.4	13.4	8.2	9.1
Chloride	0.00	3.55	0.00	1.78	0.00	0.00	0.71	0.00	0.00	0.36
	(μg/L)									
Cadmium	0.10	< 0.01	0.20	< 0.001	0.30	<0.01	0.10	<0.01	0.11	0.03
Copper	28.0	7.0	6.0	<2.0	4.1	<2.0	4.4	<2.0	40.0	<2.0
Iron	1220.0	230.0	205.0	5.0	860.0	28.0	80.0	50.0	98.0	60.0
Lead	2.0	<0.1	1.2	<0.1	5.4	<0.1	2.0	<0.1	8.5	0.2
Manganese	39.0	10.0	90.0	9.0	70.0	5.0	20.0	<10.0	15.0	<10.0
Zinc	30.0	<5.0	30.0	<5.0	30.0	<5.0	30.0	<5.0	60.0	10.0
Orthophosphate P	20.0	<1.0	25.0	<1.0	36.0	<1.0	14.0	<1.0	<1.0	<1.0
Total P	52.0	<1.0	31.0	<1.0	70.0	<1.0	54.0	<1.0	<1.0	<1.0
Organic N	720.0	<10.0	930.0	<10.0	960.0	<10.0	660.0	<10.0	210.0	<10.0
Nitrite N	3.0	<1.0	2.0	<1.0	6.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nitrate N	150.0	<10.0	110.0	<10.0	80.0	<10.0	110.0	<10.0	10.0	<10.0
Ammonia N	160.0	<10.0	170.0	<10.0	40.0	<10.0	80.0	<10.0	30.0	<10.0

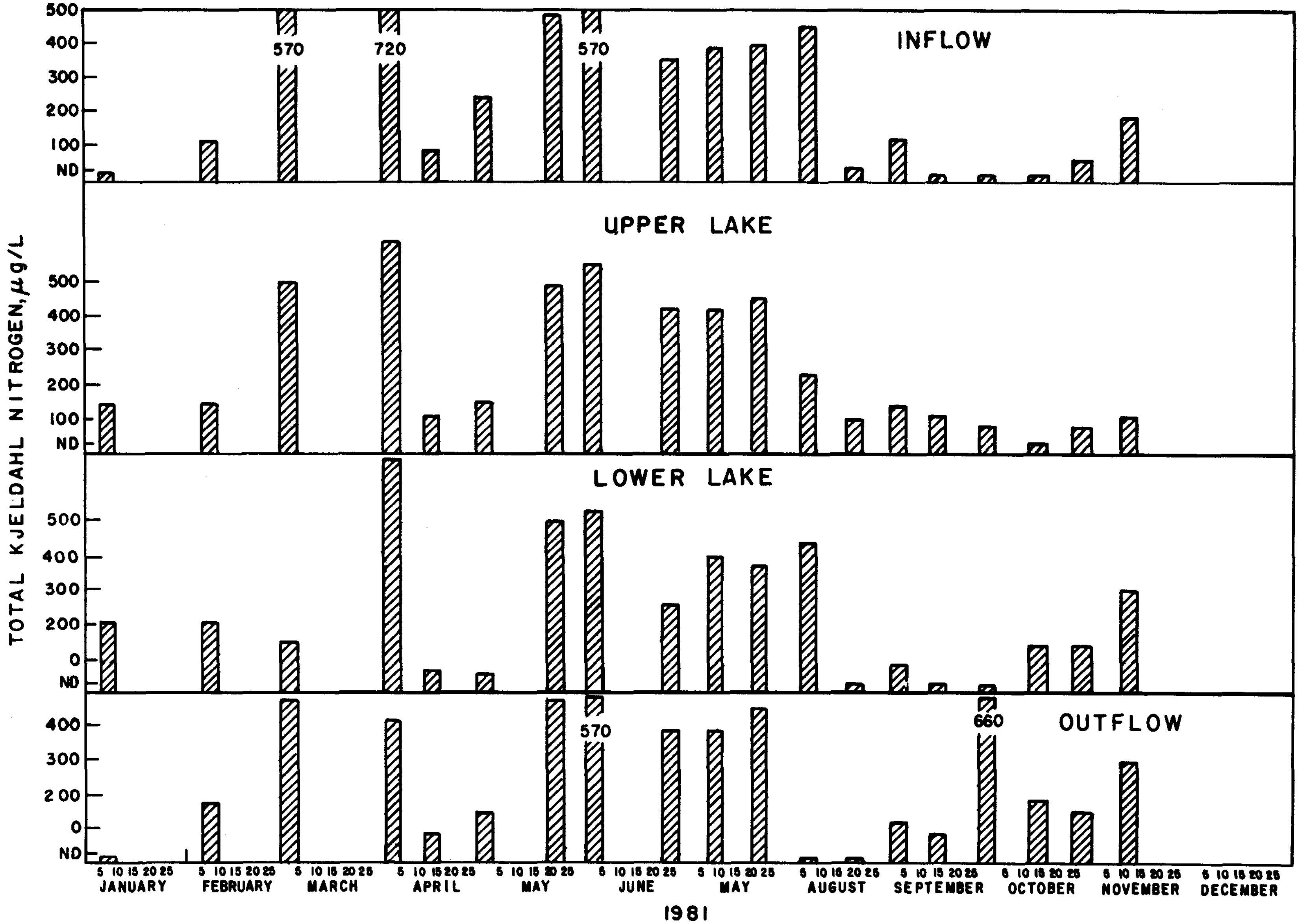


Figure 21.—Total Kjeldahl nitrogen concentration in Twin Lakes during 1981.

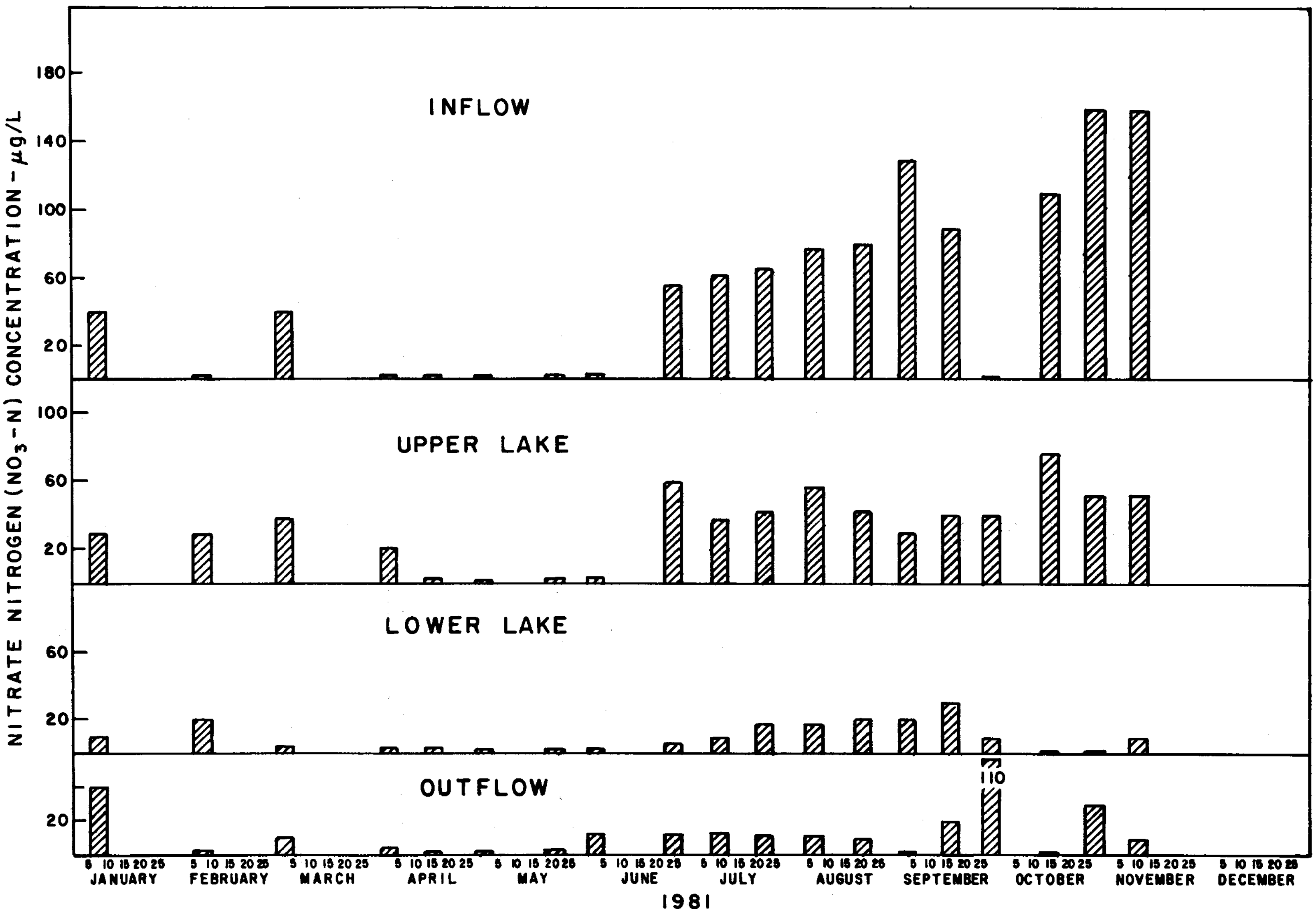


Figure 22.—Nitrate nitrogen concentration in Twin Lakes during 1981.

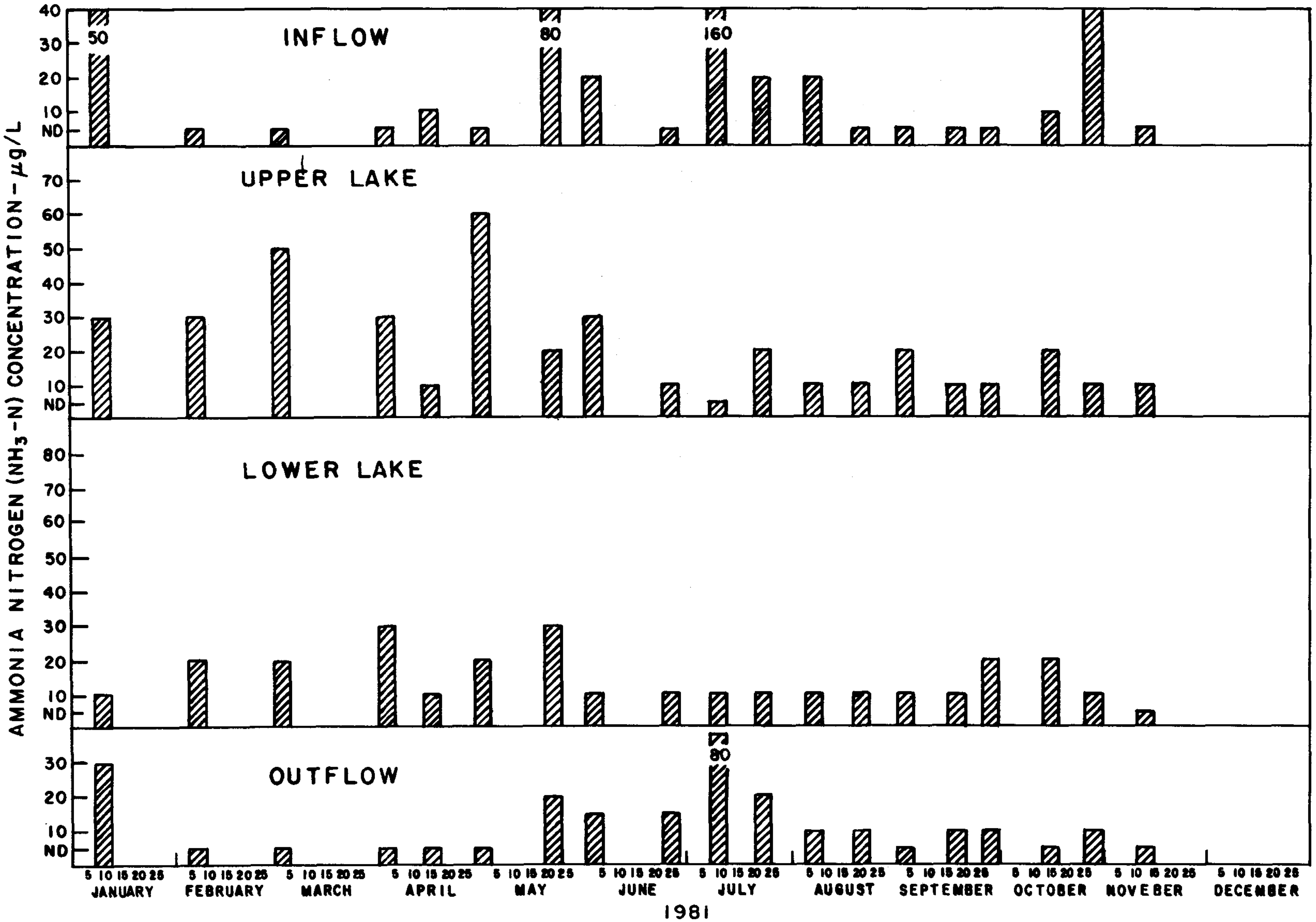


Figure 23.—Ammonia nitrogen concentration in Twin Lakes during 1981.

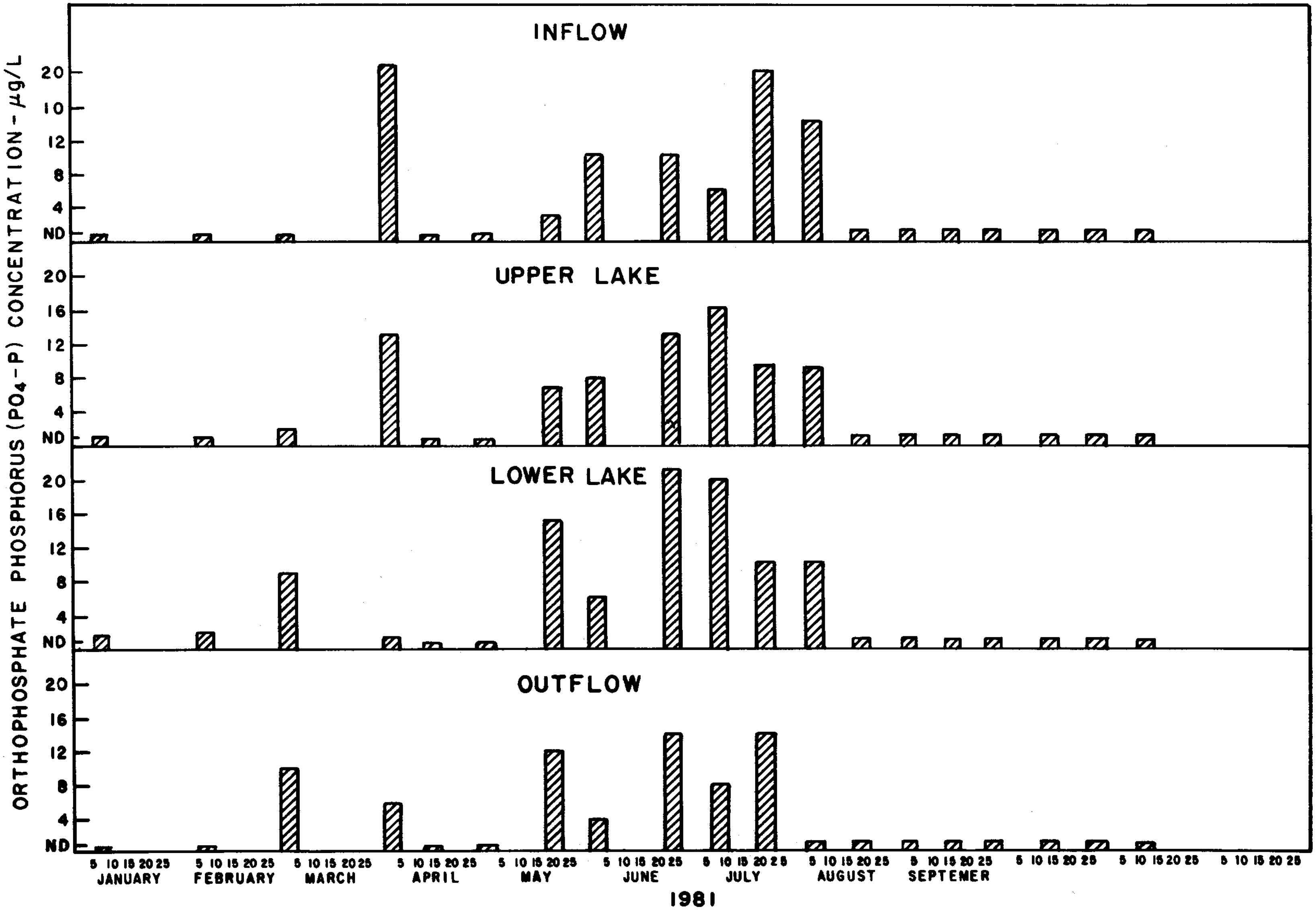


Figure 24.—Orthophosphate phosphorus concentration in Twin Lakes during 1981.

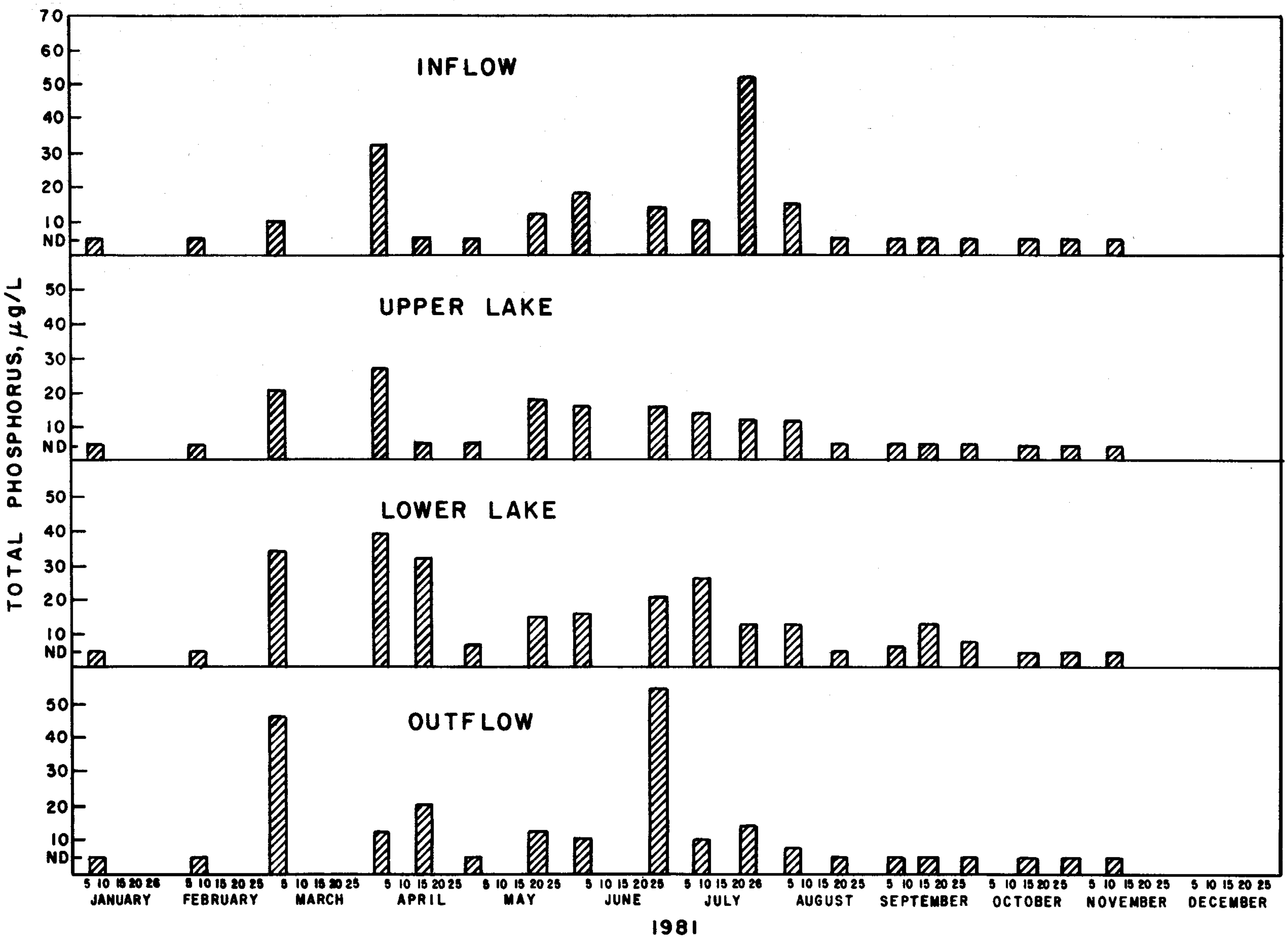


Figure 25.—Total phosphorus concentration in Twin Lakes during 1981.

extremely limiting to biological productivity at Twin Lakes. While orthophosphate phosphorus concentrations during all other years of this study were below 3 μg/L and mostly below the detectable limit of 1 μg/L, samples analyzed during mid-1981 showed concentrations up to 20 μg/L. There is some doubt in the validity of these data as we did not find a comparable increase in primary productivity nor any reason for this substantial increase. Data on the figures show a significant drop in orthophosphate phosphorus the first part of August, which was the second of two sets of 1981 water samples analyzed. Concentrations in the second set seem more realistic since they agree with the other 5 years of data, especially since 1981 was a drought year. One characteristic of drought years is that concentrations of nutrients have always been lower in those years. Data on total phosphorus concentrations show a somewhat similar trend as those described for orthophosphate phosphorus. Previously, the maximum concentration of total phosphorus found was 5 μg/L. Nearly 25 percent of the time, the concentrations were below the 1 μg/L detection limit. Data on figure 25, analyzed in the first of the two sets of samples mentioned, show total phosphorus to be as high as 50 μg/L or 10 times the previous high and often above 20 μg/L. Results from the second set of samples show more reasonable concentrations of total phosphorus during a relatively dry year. Nonetheless, all data are presented in this report with the hope that we can explain it better by the time the final reports on this project are prepared. It is still our contention that Twin Lakes are phosphorus-poor and, as past data have shown, this is supported by the fact that the biota responds dramatically to any input of phosphorus at any time of the year (see Labounty, et al., 1980 [16], and LaBounty and Sartoris, 1981 [21]).

Biological Parameters

Primary Productivity. —Primary productivity determination using the ^{14}C technique is a method for measuring the instantaneous rate at which algae are fixing carbon during cellular development. This method was used on each of the lakes on 19 sampling dates during 1981. Figure 26 shows profiles of measured primary production rates displayed volumetrically, mg C/(m^3·h). In addition, the calculated areal production rate, mgC/(m^2·h), for each of these dates is indicated at the bottom of each profile. The following are some generalizations made from the data plotted on figure 26. The lower lake, as is generally true, was more productive than the upper lake during 1981. This is especially true during years when runoff was greater than normal. Productivity was lowest in late winter for both lakes. When the ice went off, carbon fixation rates increased. Rates in the upper lake during late June were reduced by the shading and flushing influence of peak spring runoff. The rate of primary production decreased during midsummer when nutrients were effectively sealed in the hypolimnion, runoff nutrient loading was reduced, and epilimnetic nutrients were tied up in biomass. Also notable during the summer is that the primary productivity is generally greater at some depth below the surface. This is displayed on August 20 in the upper lake and on September 18 in the lower lake (fig. 26). These subsurface productivity peaks may be associated with the bottom of the epilimnion where nutrients can accumulate and light is optimum for algal reproduction and growth. As the thermocline sinks during the season, more of the bottom becomes exposed to mixing, nutrients become increasingly more dispersed into the water column, and primary productivity increases. This is evident on the September and October profiles on figure 26. At this same time, most of the production of phytoplankton is restricted to the area above 9 m. This is the euphotic zone where adequate light for production is available. Below this depth, light levels are inadequate for net production.

Figure 27 contains profiles of chlorophyll *a* biomass in the upper and lower lakes during 1981. These data represent the biomass (mg/m^3) of photosynthetically active algal pigments in the water column from the surface to 15-m depth on the indicated sampling dates. The most obvious observation from the data is that chlorophyll *a* was far more abundant in the upper lake than it was in the lower lake from mid-July until mid-September. Primary productivity studies do not support this observation. In addition, as will be seen later, actual counts of phytoplankton collected from the two lakes in 1981 do not support the observations from the chlorophyll *a* data. One possibility is that phytoplankton organisms in the upper lake contained, on the average, significantly more chlorophyll *a* than those from the lower lake. A second possibility is that the algae collected on some dates consisted of organisms small enough to pass through the 76-micron mesh net used (i.e., nannoplankton). Therefore, the chlorophyll was measured but the organisms were not counted. A third explanation, which has some data to support it, is that a huge density of algae existed in the summer of 1981 only in a very thin (10- to 20-mm) layer on top of the thermocline of the upper lake. Densities were very small in the rest of the water column. However, this "lens" of dense phytoplankton appears much more extensive on figure

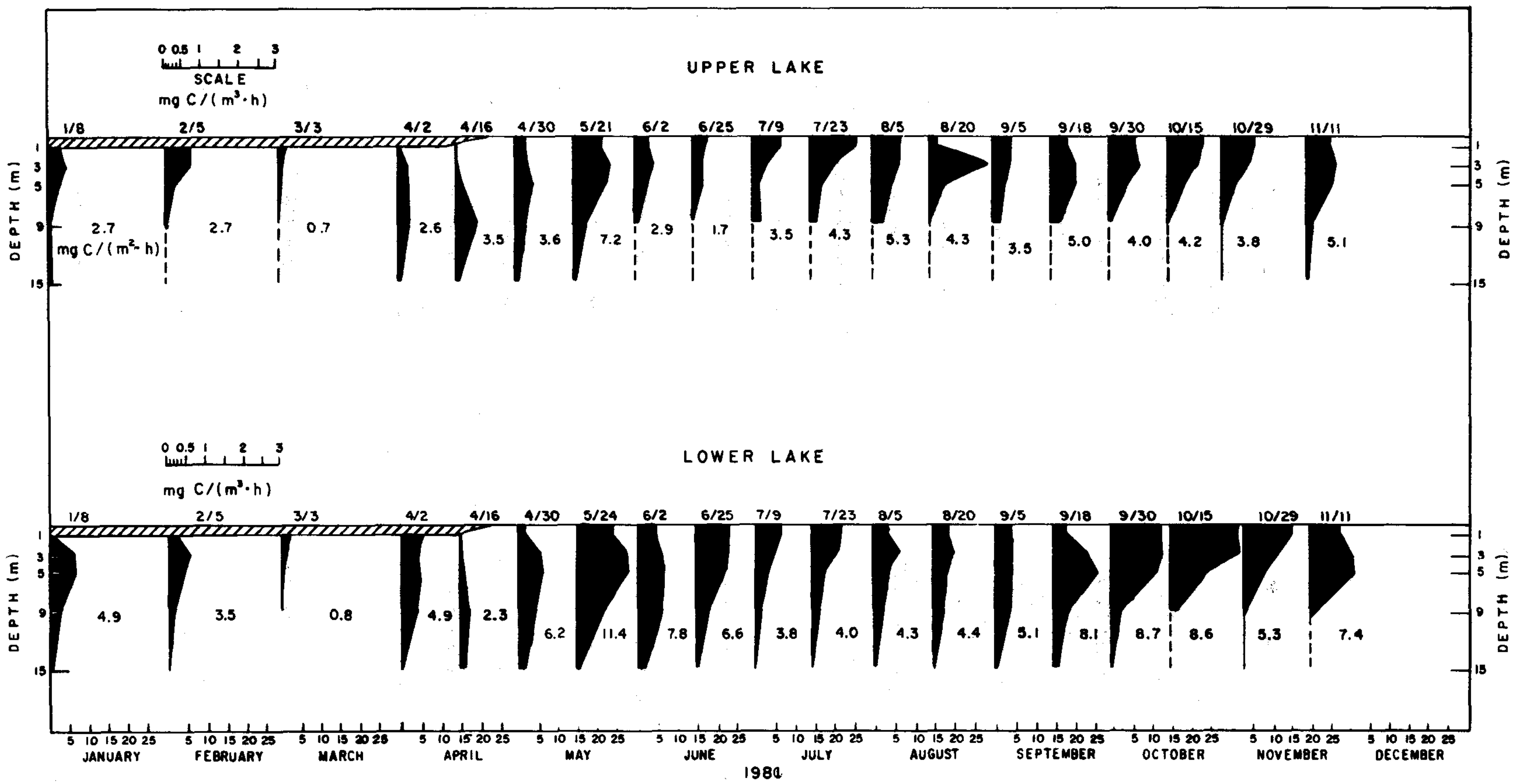


Figure 26.—Primary productivity profiles for Twin Lakes during 1981.

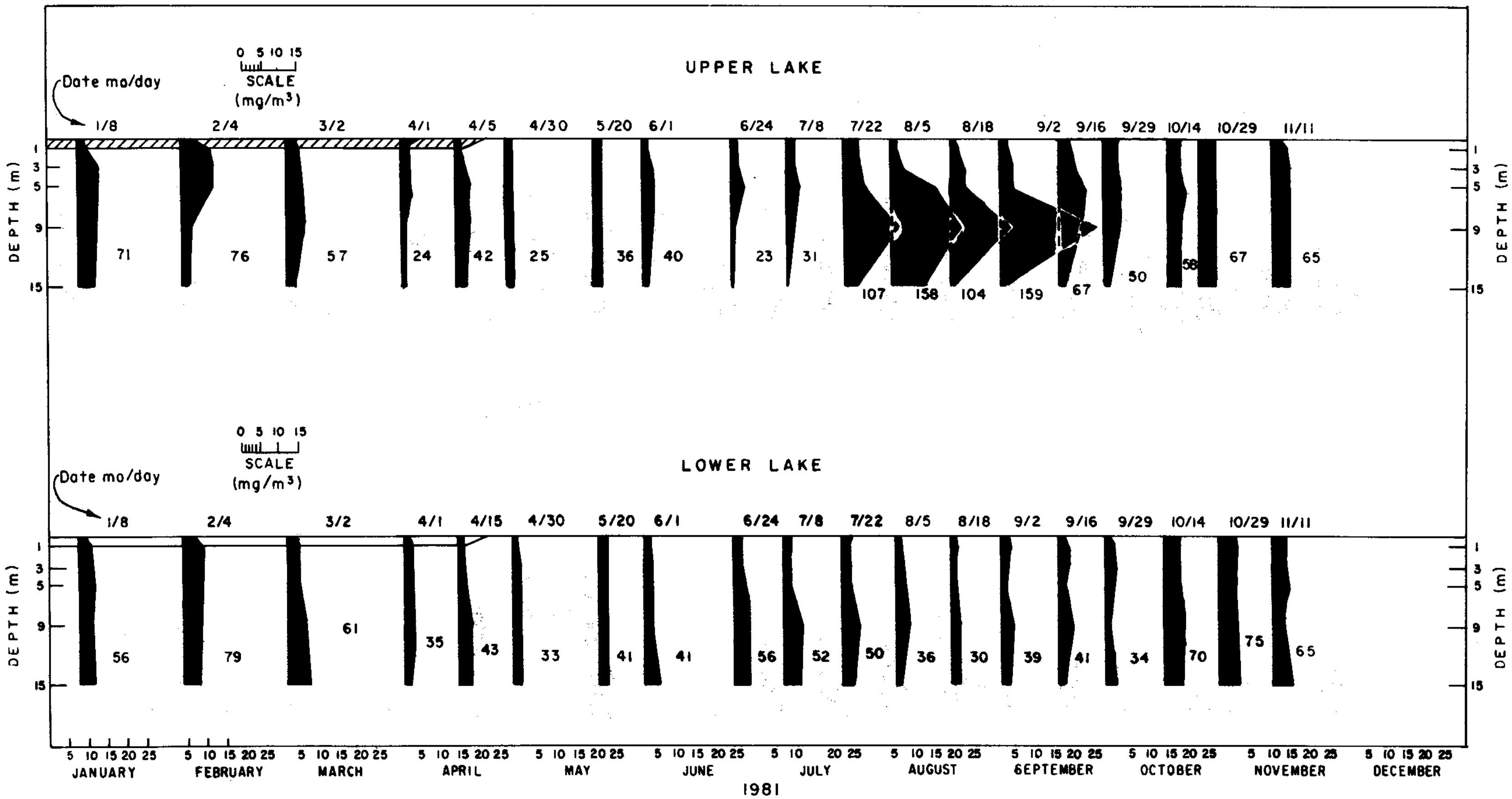


Figure 27.—Chlorophyll *a* biomass profiles from Twin Lakes during 1981.

27 than it actually was due to the way we sample for chlorophyll. Sampling is done at the surface and at 1-, 3-, 5-, 9-, and 15-m depths in an attempt to collect representative samples. These depth points on the profile are then connected in plots. The plots and formulas used to calculate areal chlorophyll then overestimate the extent of the larger chlorophyll *a* concentrations. Transmissivity and phytoplankton data support this contention with one exception (Aug. 18).

Figure 28 contains line plots of the primary production rates and chlorophyll *a* concentrations in the upper and lower lakes for 1981, calculated on the areal basis (chlorophyll *a* in mg/m^2 and primary production rate in mg $C/(m^2 \cdot h)$. Theoretically, annual trends for these two parameters should be at least somewhat similar. Even though there is some similarity between the patterns found in the upper lake, those for the lower lake are quite dissimilar. The relationship between relative values in the two lakes do not show much similarity. These differences may be due to one or more factors. One factor is that the primary productivity rate is an instantaneous measure for the time the samples are left in the lake. This is then an indicator of production for the general period during which sampling was done. Increased nutrients brought in by inflow or a rainstorm on another day could change things drastically. Also, phytoplankton produced in the epilimnion of the lower lake is susceptible to flushing since the lake has a surface outflow. The point is, several factors influence the data including our method of sampling, as discussed in the preceding paragraph.

Patterns of primary productivity displayed on figure 28 are generally similar to those of other years; that is, highest in spring and fall when turnover occurs, lowest during winter, with a low also found in midsummer when stratification is strongest. The magnitudes and range of values found during 1981 were also similar to those from other years. Figures 29 and 30 are plots of the total primary productivity for 7 of the 9 years of this study including the 9-year averages. Primary production that occurred during the ice-free months is distinguished from that which occurred during the months when the lakes were covered with ice. Overall, the average production rate for the upper and lower lakes is about 12 and 26 g $C/(m^2 \cdot a)$, respectively. The lower lake has been, on the average, more than twice as productive as the upper lake. The rate of primary production was significantly higher in the upper lake during years of low runoff than it was during years when runoff was high. The wet and dry years since 1977 are noted on figure 29. The influence of wet and dry years is reversed in the lower lake, but the resultant difference in primary production is hardly significant (fig. 30). This is due to the upper lake being highly influenced by runoff while the lower lake is not. The upper lake is severely flushed in June by high runoff, while at the same time it has reduced clarity due to sediment-laden inflow. The upper lake has greater water clarity and is not flushed so severely during years of low runoff, which then tends to make it the catch basin for nutrients which would otherwise be carried to the lower lake. At the same time, the upper lake becomes warmer because of the reduced inflow of colder water. The upper and lower lakes are similar in that, on the average, about 70 percent of all primary production occurs during the ice-free months. This percentage drops significantly to about 60 percent in the upper lake during years when runoff is lowest. The reasons for the increased winter production during dry years in the upper lake are not yet clear. However, the influence of runoff volume on primary production is tremendous and cannot be overemphasized. The 1981 data reflect this influence. That is, primary production and chlorophyll *a* concentration in the upper lake was greater in 1981, about 15g $C/(m^2 \cdot a)$ than it was for the last 4 years when winter measurements were made. At the same time, runoff was below average.

Figures 31 and 32 summarize data collected during 1981 on the primary production rate, light extinction coefficient (with a reversed scale to reflect increased and decreased water clarity), water temperature at 1 m, mean ambient light, concentration of orthophosphate phosphorus, and concentration of total Kjeldahl nitrogen. These data are presented to illustrate relationships. Only one relationship is easily seen from the data; that is, the decrese in rate of primary production and decrease in light extinction coefficient in the upper lake during June. Reasons for this relationship were previously discussed. The light extinction coefficient does not seem to influence the rate of primary production as much in the lower lake. Another observation is that water temperature, although probably a determining factor as to the kind of algae produced, does not seem to have an influence on the quantity of algae produced, or on when it is produced. Similarly, it is difficult to see any influence of nutrient concentrations on algal production. However, analysis of data from past years has established the fact that the lakes are phosphorus limiting (LaBounty, et al., 1980 [16], and LaBounty and Sartoris, 1981 [21]). There is really no reason to think differently at this time.

Plankton Abundance. — Graphs in this section present data on the trends and composition of

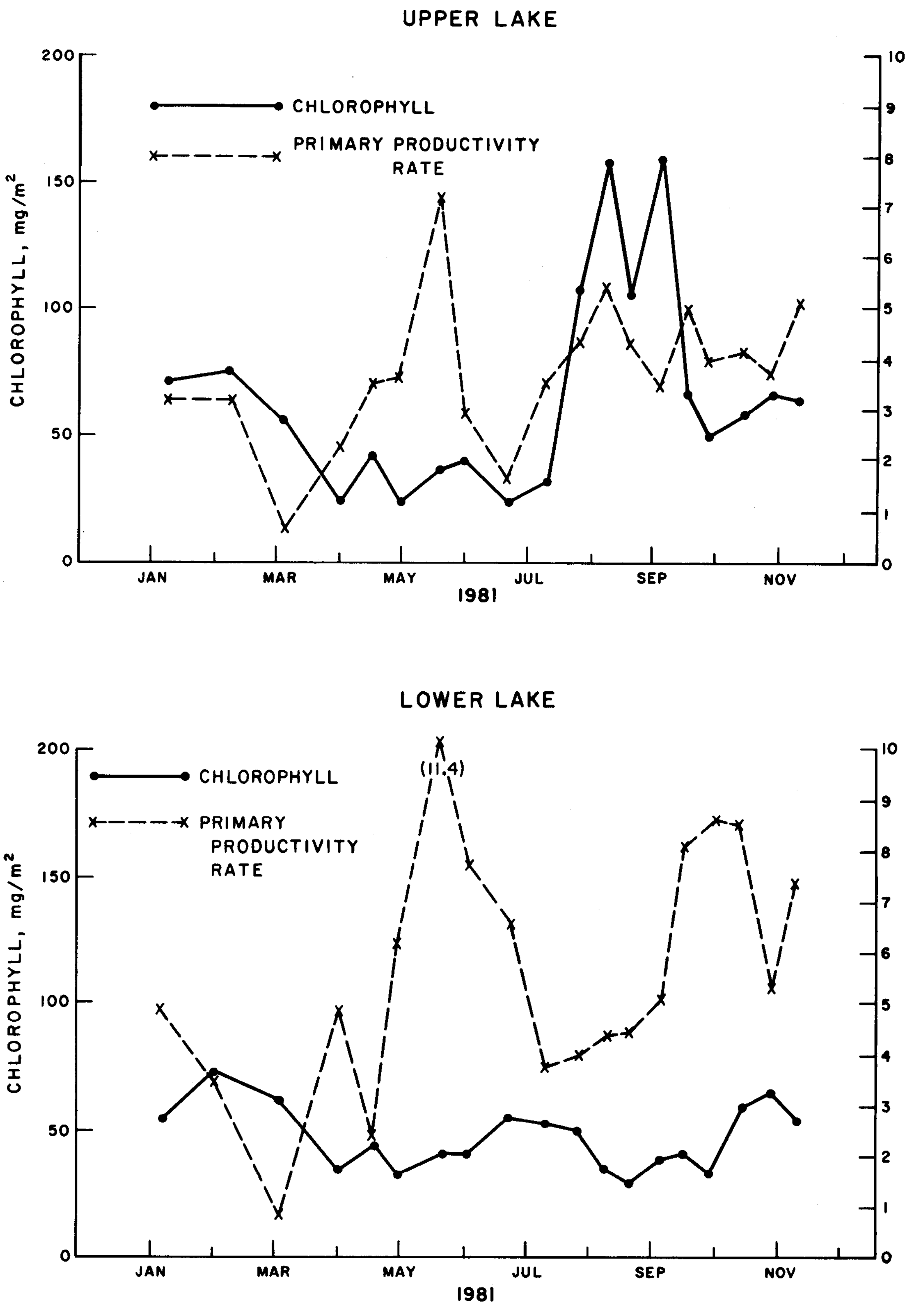


Figure 28.—Areal primary productivity and chlorophyll *a* biomass from Twin Lakes during 1981.

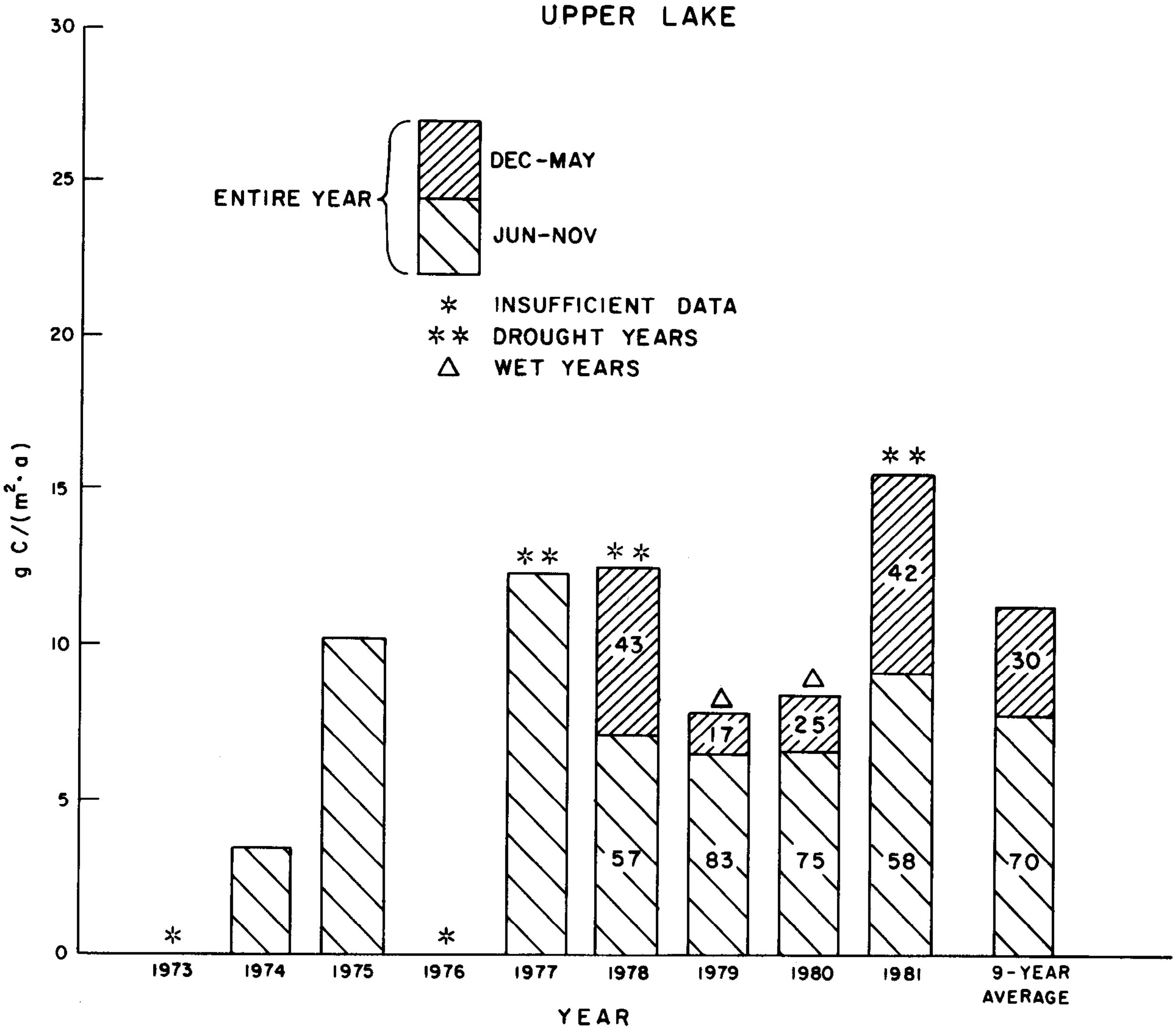


Figure 29.—Annual areal primary productivity in upper lake, 1973-81.

phytoplankton and zooplankton populations of the upper and lower lakes during 1981. Figure 33 includes data on total zooplankton and phytoplankton populations, and two observations are notable. One, densities of plankton in the upper lake were significantly less than those in the lower lake. As previously stated, these data are supported by the primary productivity data. The second notable point is that cycles of phytoplankton and zooplankton populations in the lower lake alternate. That is, the peak density of phytoplankton drops significantly when the zooplankton density begins to peak. This raises the queston of whether the drop in phytoplankton density resulted from a die off or predation by zooplankton, or if the phytoplankton supports the zooplankton. In other years the magnitude of the zooplankton population has always been supported by the same magnitude of the phytoplankton population. However, the cycling has not always been so well defined as in 1981. Data plots on figure 33 for the upper lake show little, if any, pattern. Phytoplankton densities ranged from a low of about 700 organisms per liter in January and again in October, to a high of almost 5000 organisms per liter in September. The September bloom was 99 percent *Dinobryon*, which was the dominant species in the upper lake for 10 months of the year (fig. 34). Phytoplankton densities in the lower lake ranged from a low density of less than 200 organisms per liter in early September to over 18 000 organisms per liter in March and over 15 000 organisms per liter in April (fig. 33). The algal bloom in March was *Synedra,* and *Asterionella* in April (fig. 34). By late September, *Dinobryon* was the dominant alga species. Phytoplankton concentrations during 1980 ranged from 1 to 1000 organisms per liter in the upper lake and from 28 to just over 13 000 organisms per liter in the lower lake. Thus, the flora was

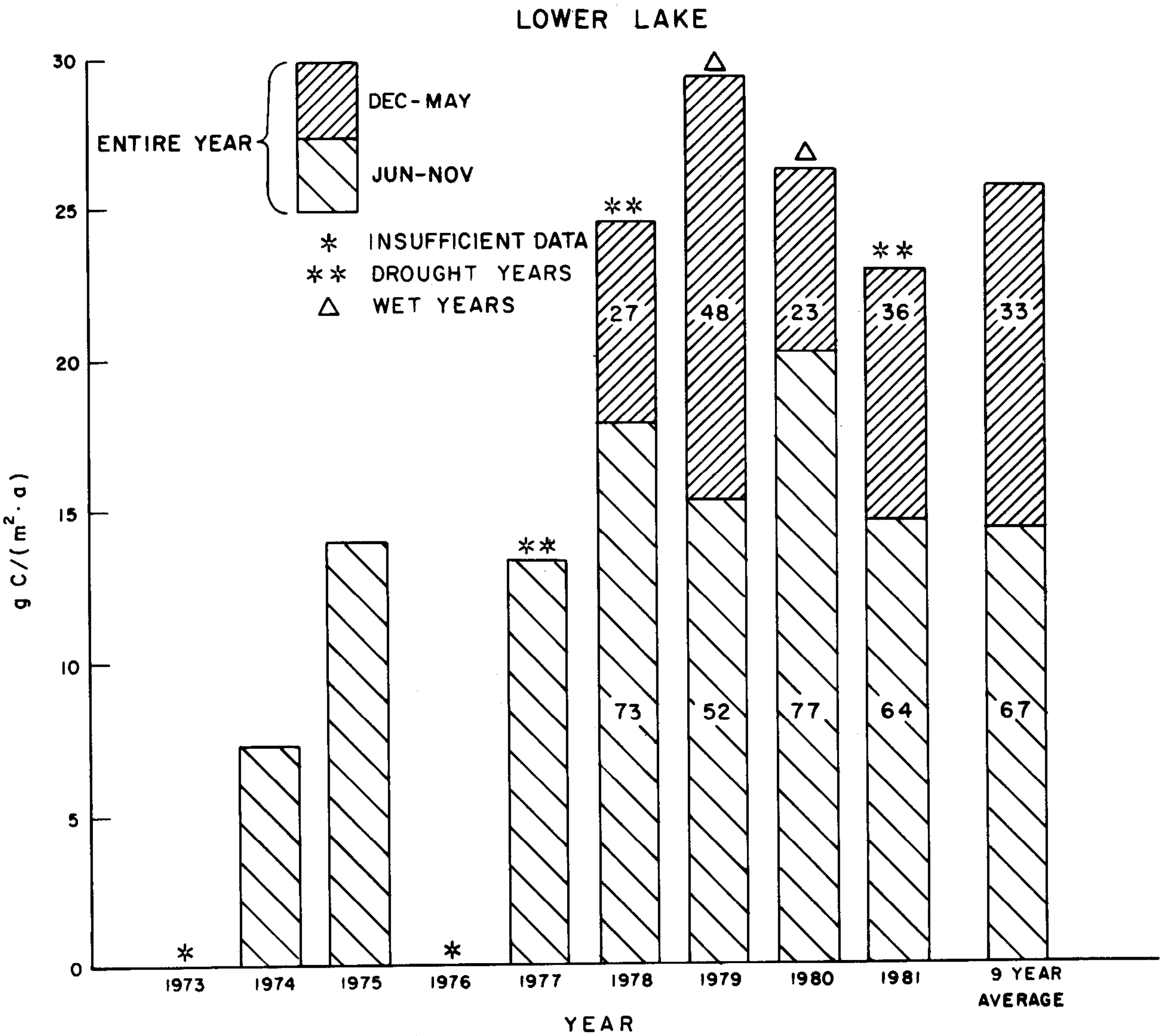


Figure 30.—Annual areal primary productivity in lower lake, 1973-81.

somewhat richer in both lakes during 1981 than in 1980.

Four kinds of zooplankton are common in Twin Lakes: mysis shrimp, cladocerans (water fleas), copepods, and rotifers. Mysis *(Mysis relicta)* is a nocturnal species and, therefore, will show up in samples of plankton collected during the night hours in the littoral zone. They are considered in this report as part of the benthos since they dwell on the bottom during the day.

Zooplankton densities in the upper lake ranged from just over 4 individuals per liter in mid-April to over 53 individuals per liter in late July (fig. 33). Rotifers dominated the pelagic zooplankton population most of the year. *Cyclops, Diaptomus,* and copepod nauplii made up most of the rest of the zooplankton fauna and, at times, they even dominated (fig. 35). Densities of zooplankton in the lower lake during 1981 ranged from a low of 16 individuals per liter in early September to a high of 116 individuals per liter in July (fig. 33). As in the upper lake, rotifers dominated most of the time. Copepods, especially *Cyclops* and nauplii, also were abundant (fig. 35). Table 9 contains a comparison of zooplankton densities in Twin Lakes during the past 3 years. Densities in the upper lake were similar during 1980 and 1981,

Table 9. — *Comparison of average zooplankton densities, 1979-81*

Year	Individuals per liter: Upper lake	Lower lake
1979	13	47
1980	23	46
1981	22	53

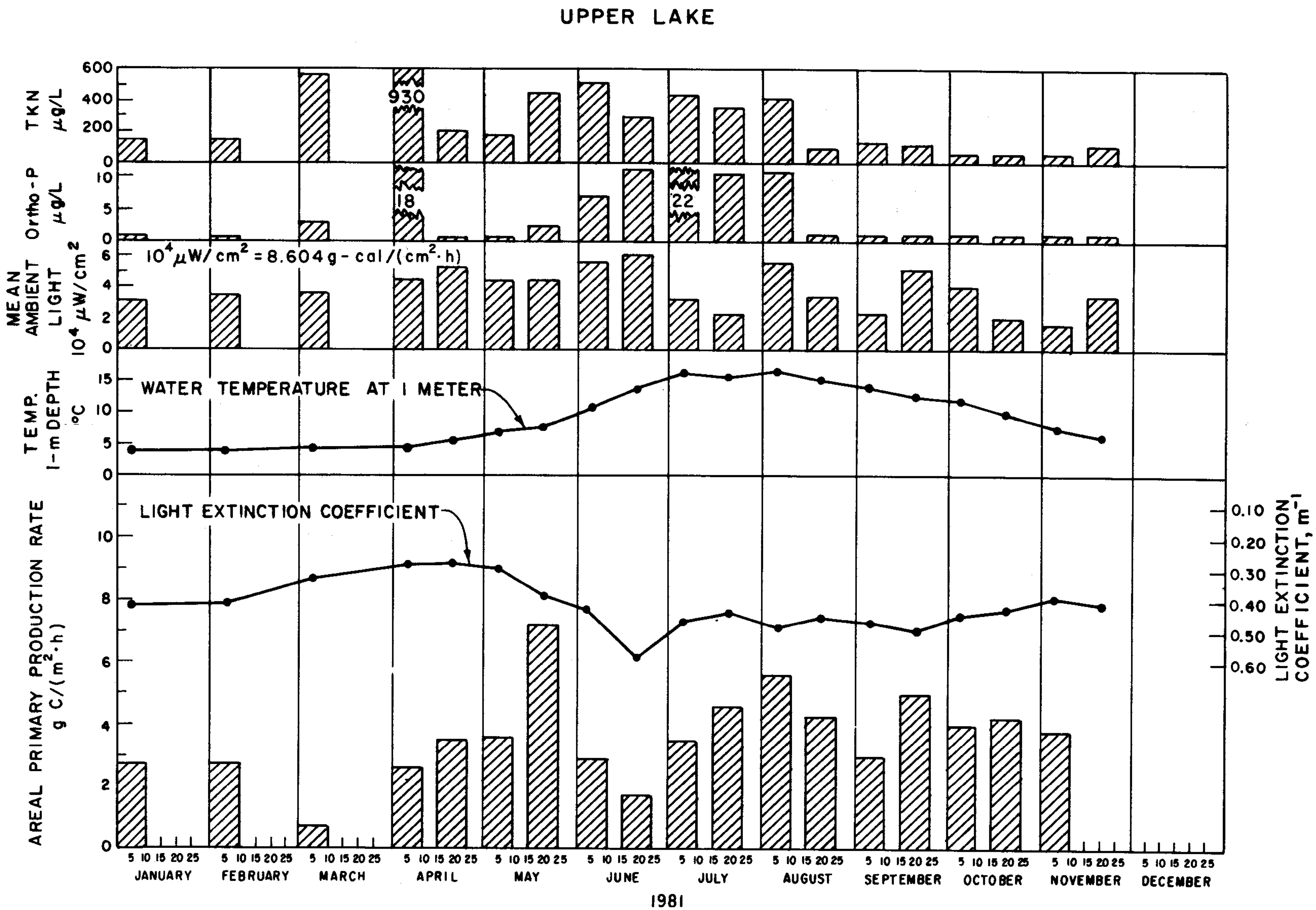


Figure 31.—Annual plot of six limnological parameters for upper lake during 1981.

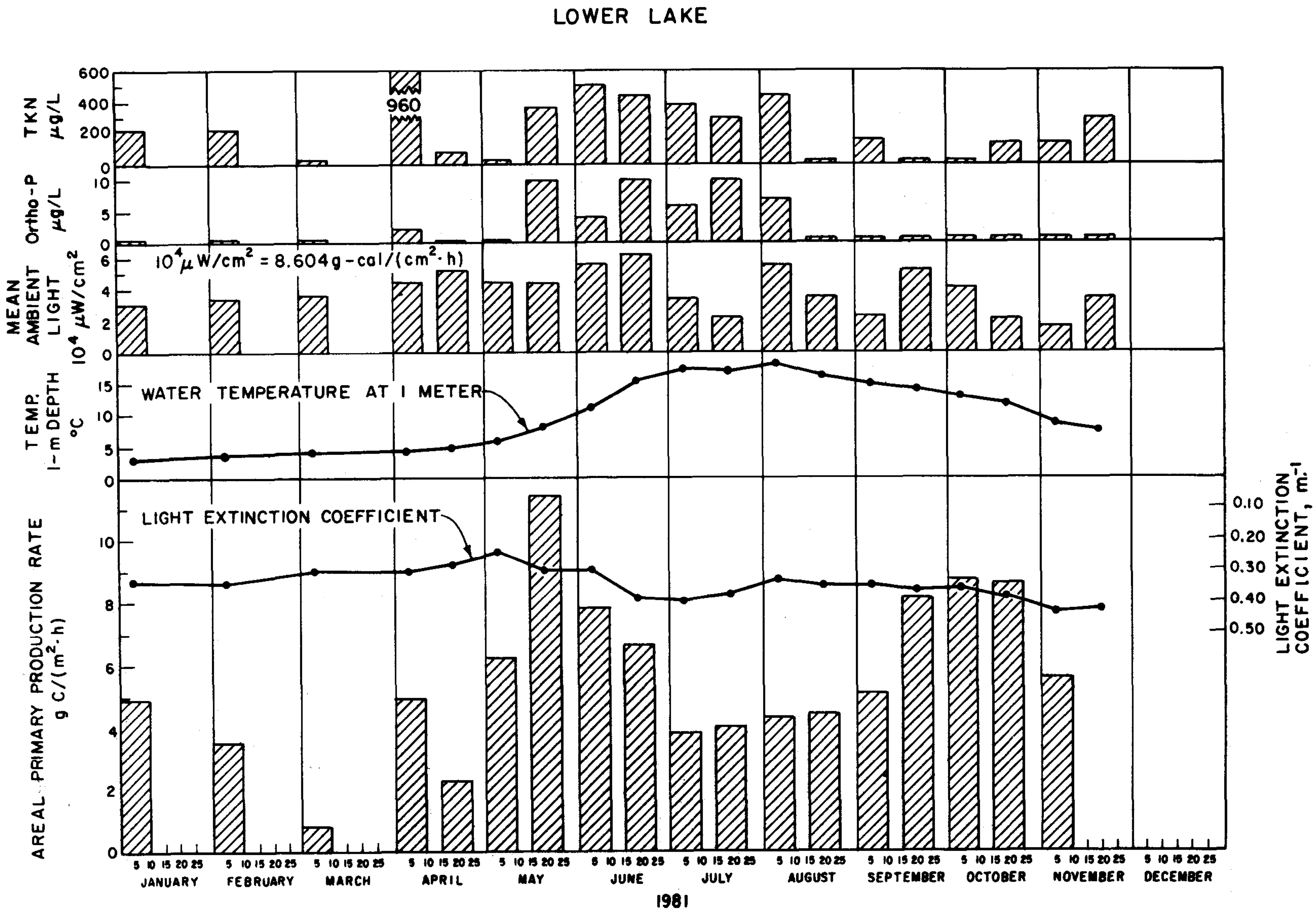


Figure 32.—Annual plot of six limnological parameters for lower lake during 1981.

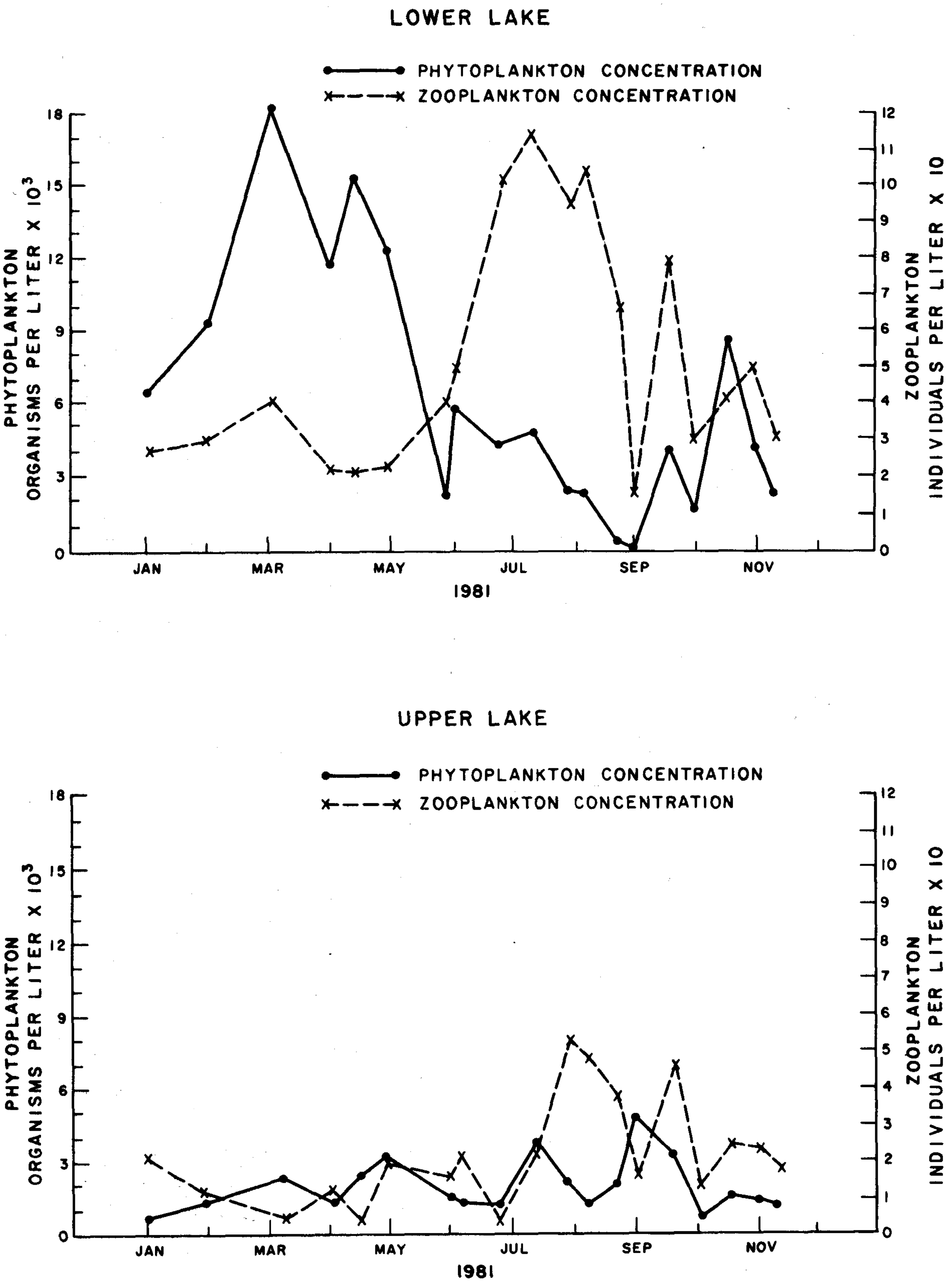


Figure 33.—Total phytoplankton and zooplankton concentrations in Twin Lakes during 1981.

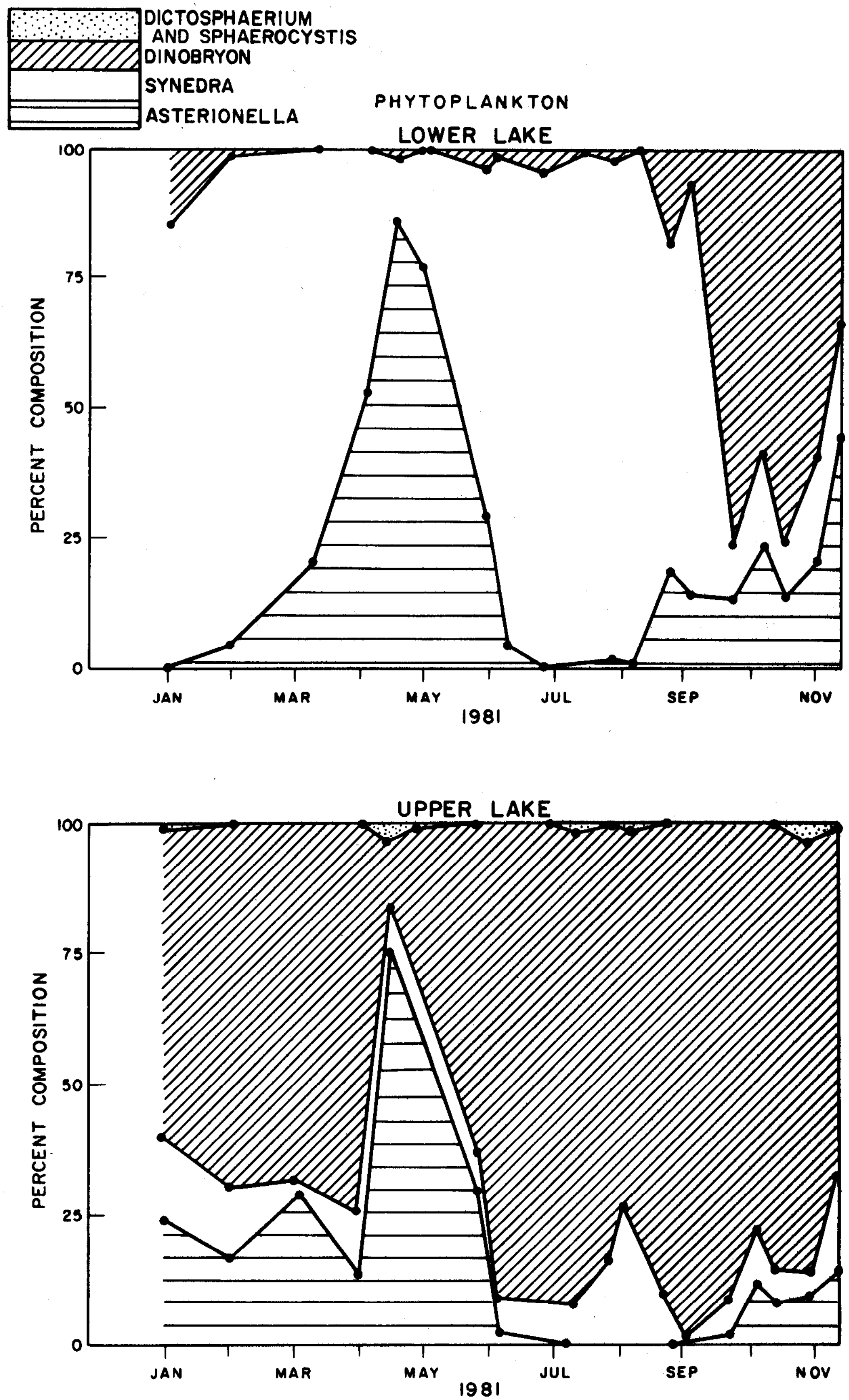


Figure 34.—Percent composition of phytoplankton collected from Twin Lakes during 1981.

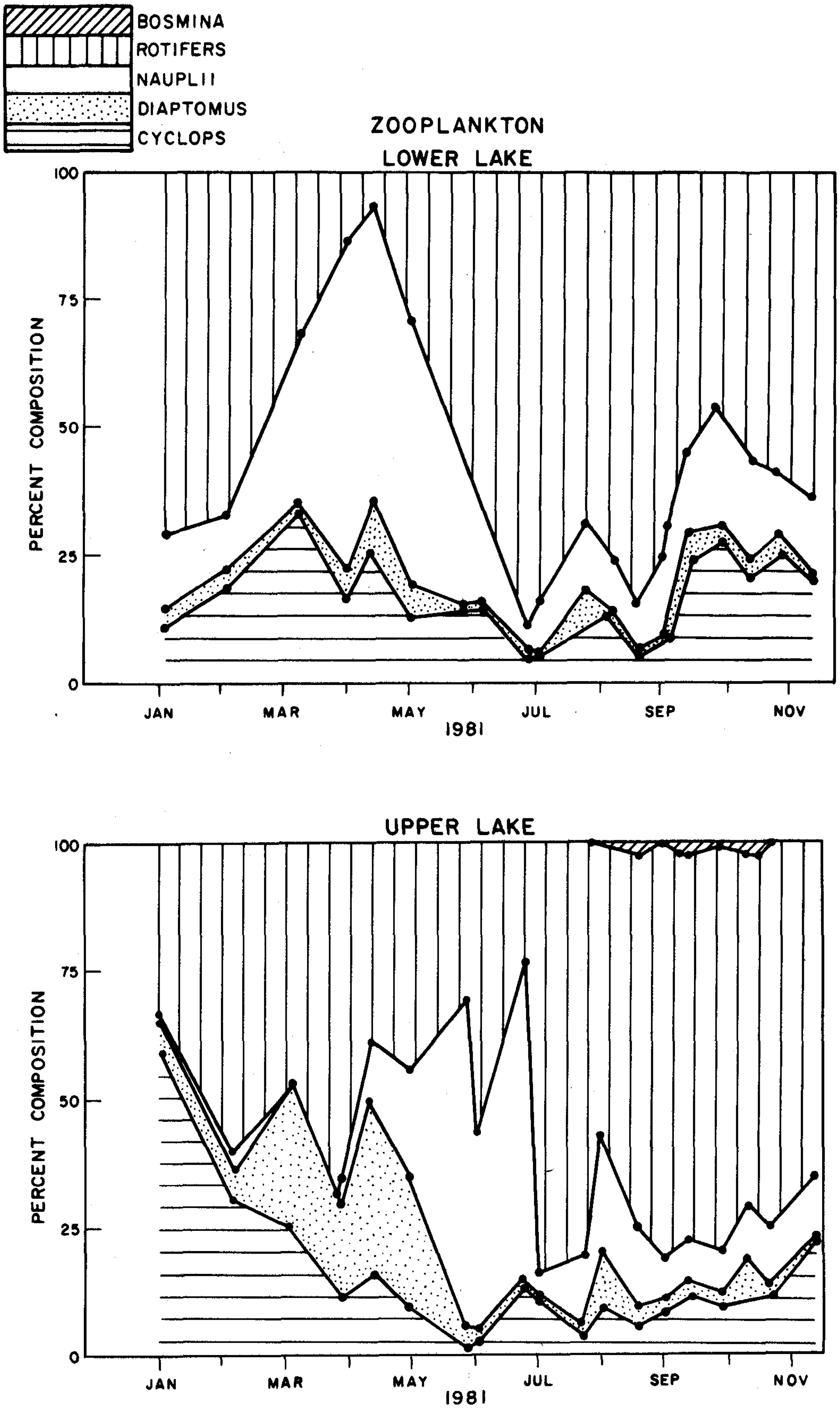


Figure 35.—Percent composition of zooplankton collected from Twin Lakes during 1981.

and over 60 percent greater than the average density for 1979. Concentrations of zooplankton in the lower lake were 10 to 15 percent greater in 1981 than in 1979 or 1980. Mysids, copepods, and rotifers were the most abundant kinds of zooplankton found, with cladocerans occurring only occasionally and in the form of the relatively small bodied species *Bosmina*. Juday (1906) [31] reported that cladocerans (including *Daphnia* spp.) made up from 20 to 45 percent of the adult zooplankton population during 1902 and 1903. From 1974 through 1981, cladocerans (exclusively *Bosmina*) made up no more than 1 percent of the zooplankton population except during one sampling period (August 1980) when it made up 5 percent of the upper lake's zooplankton fauna. On several other dates, it made up 1 percent or less of the population of each lake; however, this only occurred after late July. The near elimination of cladocerans from Twin Lakes has occurred since mysis shrimp were introduced in 1958. Mysis are extremely predaceous upon species of zooplankton that are smaller bodied than they are. Goldman, et al., (1979) [32] described a similar alteration in the zooplankton fauna following the introduction of mysis in Lake Tahoe. All of the surrounding waters to Twin Lakes, ponds and lakes alike, at times contain large densities of *Daphnia* spp. and other cladoceran species. Turquoise Reservoir, a new source of water that is being used for generation of power, also contains large densities of *Daphnia*. Large densities have also been found in the Mt. Elbert Forebay. In addition, large densities of *Mysis relicta* were found in the forebay after pumping began in mid-1981. This was after the largest densities of *Daphnia* occurred in the forebay. In the future, some *Daphnia* will get into Twin Lakes. The fate of these cladocerans can only be speculated upon. Predation in the forebay upon cladocerans by mysis is likely and, whether predation occurs and whether mysis become established in the forebay, are two of the more curious aspects of this study. Data from 1981 have only established that mysis were very abundant in the forebay and that at least some *Daphnia* get into Twin Lakes.

Benthos. — Four types of benthic animals are collected in dredge samples from Twin Lakes. One type, chironomids, or the nonbiting midges (family, Chironomidae-Tendipedae), are representatives of the order of flies (Diptera) and are best known as the predominant insect of lake sediments (Mundie, 1957) [33]. They are sometimes present in great numbers and may be detritus, animal, or plant feeders taking part in the exchange of substances within the sediments and between them and the outside water. A second type, oligochaetes (family Oligochaeta), are aquatic earthworms that, like chironomids, burrow in the bottom sediments and take part in the exchange of substances within the sediments and between them and the outside water. Pea (fingernail) clams (family, Sphaeriidae) are a third type of benthic animals and are part of a group of very small bivalved freshwater organisms with marine ancestry (Cole, 1979) [34]. Clams found in Twin Lakes are of the genus *Pisidium*, the tiny pea clam. This genus is represented at Twin Lakes by two species: the nearly worldwide *Pisidium casertanum* (Poli), found in a wide range of habitats, and the North American *P. pauperculum* Sterki, limited to lakes and large streams (personal communication, Dr. Dwight W. Taylor, Pacific Marine Station, Dillon Beach, Calif.). The fourth type of benthos in Twin Lakes is *Mysis relicta* Loven (order Mysidacea), which is also referred to as opossum shrimp, mysis shrimp, or just mysis. These animals are considered as benthos when they are on the lake bottom during daylight hours, and are considered as plankton when they are in the pelagic zone during the night. Mysis shrimp resemble transparent crayfish and reach maximum lengths of about 3 cm. The mysis was introduced into Twin Lakes in 1958 as a potential food source for the introduced lake trout, *Salvelinus namaycush* Walbaum (Klein, 1957 [35]; and Nesler, 1981 [19]). This introduction was extremely successful. Nesler (1981) [19] reported densities in Twin Lakes of up to 510 per square meter using a benthic, sled-type trawl.

Table 10 summarizes the benthos data collected during 1981, and table 11 compares the abundance of benthos over the past 4 years. Figures 36 through 39 are graphic presentations of benthos data from 1981. The mean, standard deviation, and range of each of the four kinds of benthos are plotted and compared over the past 3 years on figures 40 and 41. The benthos in the upper lake has not changed much over the past 3 years (fig. 40). Oligochaetes are the most abundant (2.6 to 1 chironomids). However, the biomass of chironomids in the upper lake is over three times that of all the other benthos combined. In 1981, the biomass of chrionomids increased significantly over that of 1980 in the upper lake, but the abundance dropped somewhat (fig. 40). This indicates a more mature chironomid population which is to be expected since the runoff was such that the habitat of this animal would be disturbed to any significant degree (e.g., by flushing and severe siltation).

Composition of benthos in the lower lake changed markedly from that of the previous 2 years (fig. 41), and two major changes are notable. First, pea

Table 10. — *Summary of benthos data from Twin Lakes during 1981*

Station	Organism	Avg. no. per square meter (38 samples)	Avg. dry mass, g/m^2 (38 samples)
2	Chironomids	578	0.94
	Oligochaetes	409	0.15
	Pisidium spp.	703	0.26
	Mysis relicta	14	0.02
4	Chironomids	617	1.32
	Oligochaetes	1626	0.43
	Pisidium spp.	7	<0.01
	Mysis relicta	11	0.01

Table 11. — *Comparison of average abundances of benthic fauna (excluding mollusks) at Twin Lakes, 1978-81*

Station	Average abundances (number per square meter)			
	1978 (N = 28)	1979 (N = 34)	1980 (N = 28)	1981 (N = 38)
2	1375	2453	2203	986
4	2114	1814	2740	2243

N = Number of samples taken.

clams, *Pisidium* spp., were the most abundant benthos in 1981, about 18 percent more abundant than chironomids. This has not been true at Twin Lakes since 1974. Second, chironomids were significantly less abundant in 1981, with a lower biomass than during either 1979 or 1980. Reasons for this are not clear. This may be a natural event, or it could be related to powerplant operation. The latter reason is supported by data on figure 36, which shows a significant drop in abundance and biomass of chironomids in the lower lake in July when powerplant operation began. This same drop did not occur in the upper lake, and it is assumed that the population there remains constant. It is unknown at this time what specifically caused the change. It could be that the powerplant caused some turbulence or the fact that ecological conditions were changed because of powerplant operation. However, at this time, we can only speculate. Another year's data will be helpful in delineating the cause of this rapid decline in the population of chironomids in the lower lake. Data on figures 37 through 39 show trends in the population densities of oligochaetes, pea clams, and mysis shrimp during 1981. In 1981, oligochaetes (fig. 37) showed a trend of increasing population in the upper lake and a small decreasing population in the lower lake. Figure 38 shows the difference between the upper and lower lakes in the abundance of pea clams. There have been years (1973-76) when no clams were collected from the upper lake. Conditions in the upper lake apparently do not favor development of this species. The continuing deposition of sediment due to spring runoff may cause some effect on habitat that does not favor pea clams in the upper lake. However, through 1981, conditions in the lower lake have been quite favorable for pea clams.

Abundance and biomass data for mysis shrimp collected with the benthic dredge during 1981 are shown on figure 39. There is limited value to these data because of the collection method. Nesler (1981) [19] presents the most accurate analysis of the relative abundance of mysis in Twin Lakes based on data obtained using a benthic trawl. He reports that densities of mysis, varying considerably for the 204 samples collected in 1977-79, ranged from 0 to 355 per square meter in 1981. Densities were greatest at the deep lower lake sampling locations. The cyclic pattern in abundance of mysis, as described by Nesler, reflect that of zooplankton species as a whole.

Other forms of benthos not yet mentioned do exist in Twin Lakes. These include benthic cladoceran (*Alona* sp.), gastropods, Trichoptera, Homoptera, Ephemeroptera, and amphipods (Krieger, 1980) [12]. These forms were all found in stomachs of suckers, which are a benthic feeding fish found abundantly in Twin Lakes. The conventional methods of collecting samples of benthic muds with dredges and straining them through sieves are not conducive to successful collection of these forms. In addition, many of these forms are associated both with shallow water and aquatic macrophytes. Our samples are taken at the deepest points in the lakes and are thus results representative of a deep lake environment.

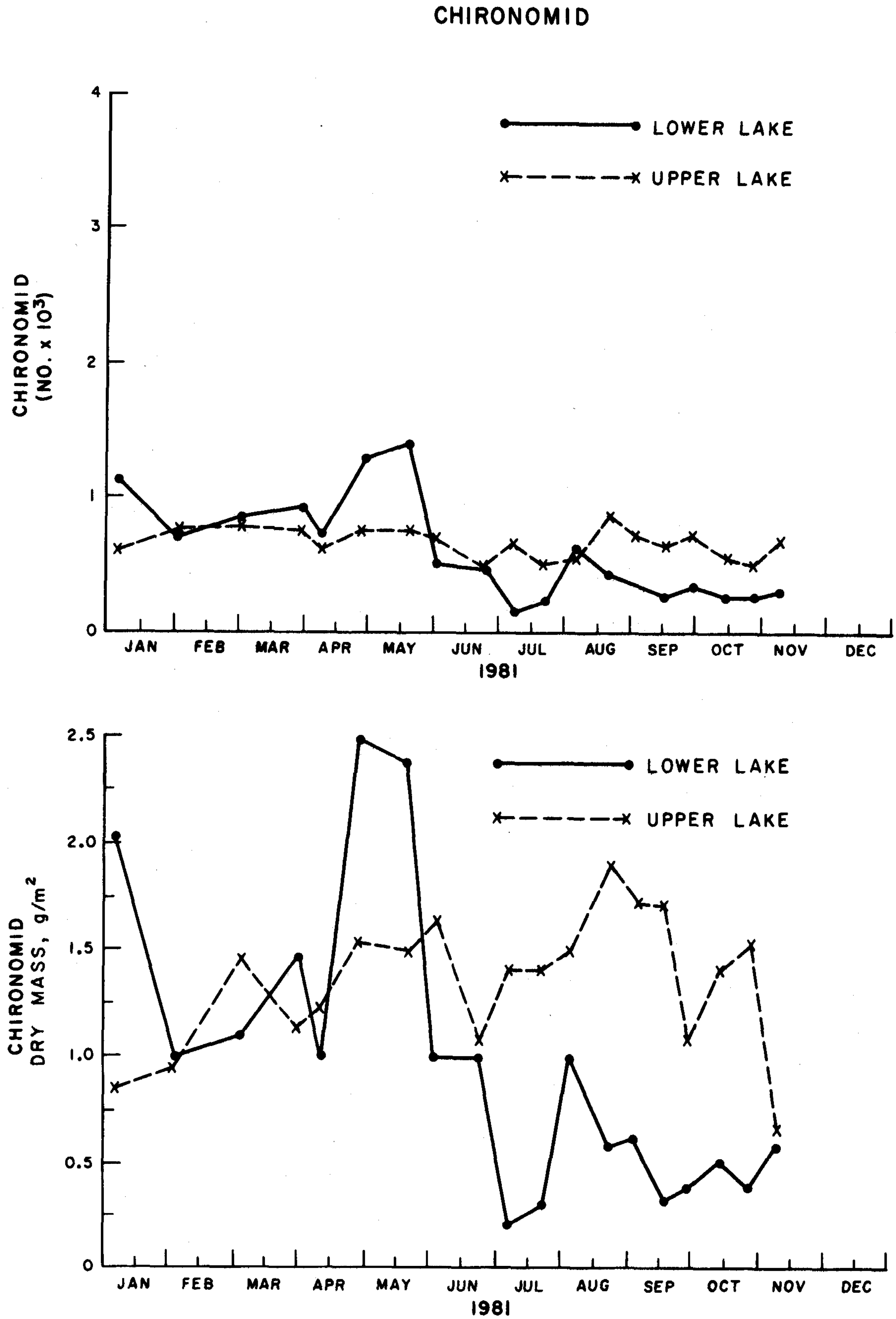


Figure 36.—Abundance and biomass of chironomid larvae in Twin Lakes during 1981.

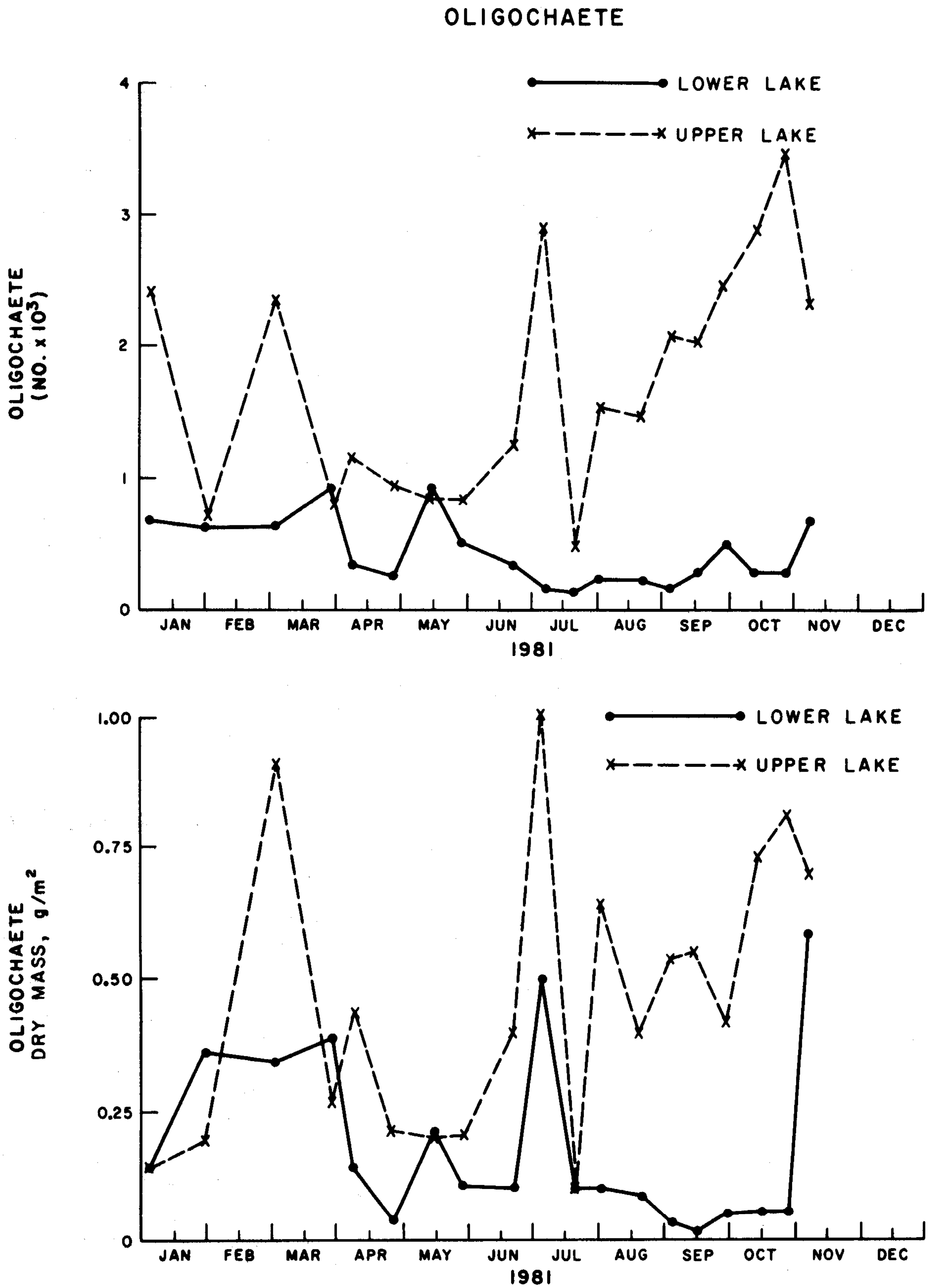


Figure 37.—Abundance and biomass of oligochaetes in Twin Lakes during 1981.

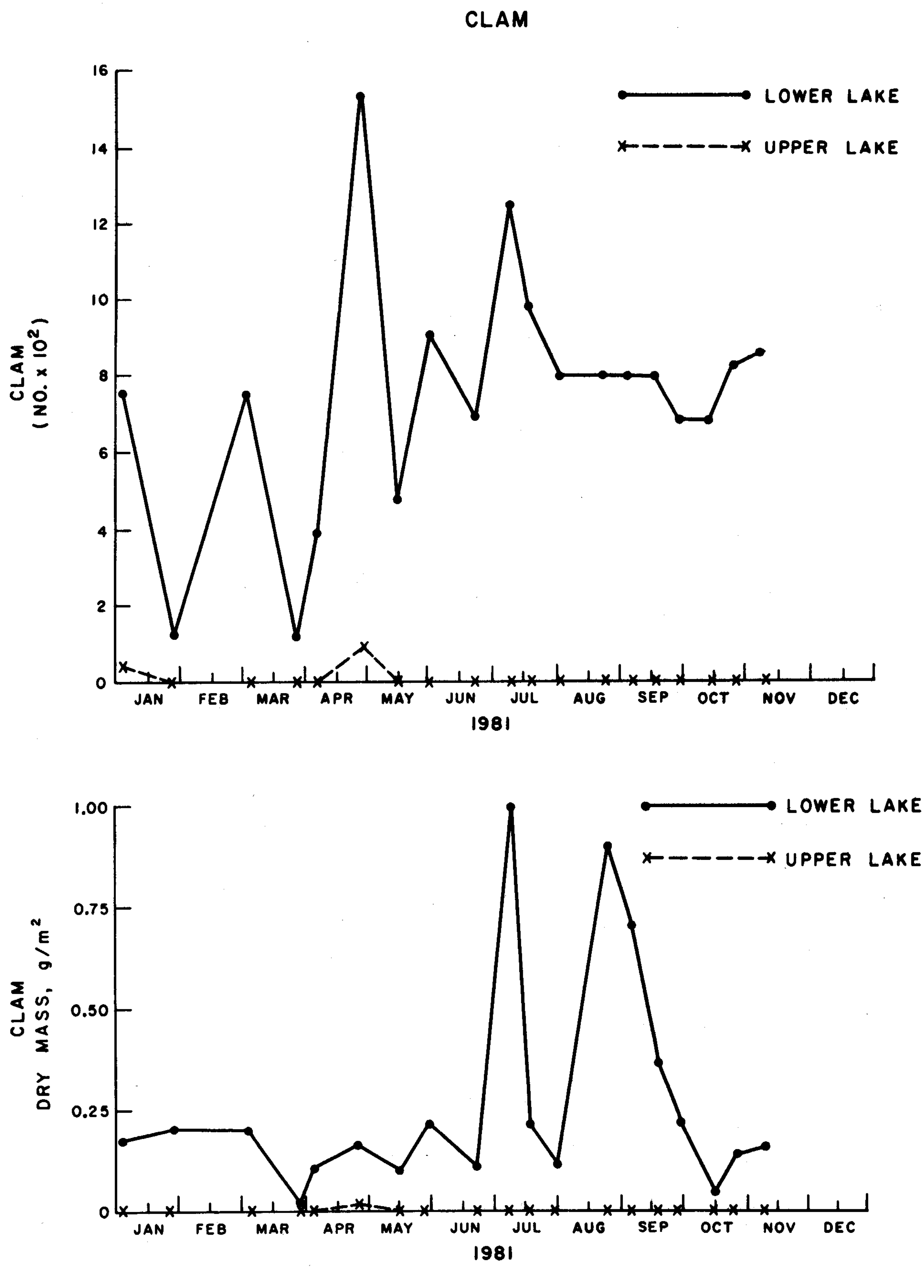


Figure 38.—Abundance and biomass of pea clams in Twin Lakes during 1981.

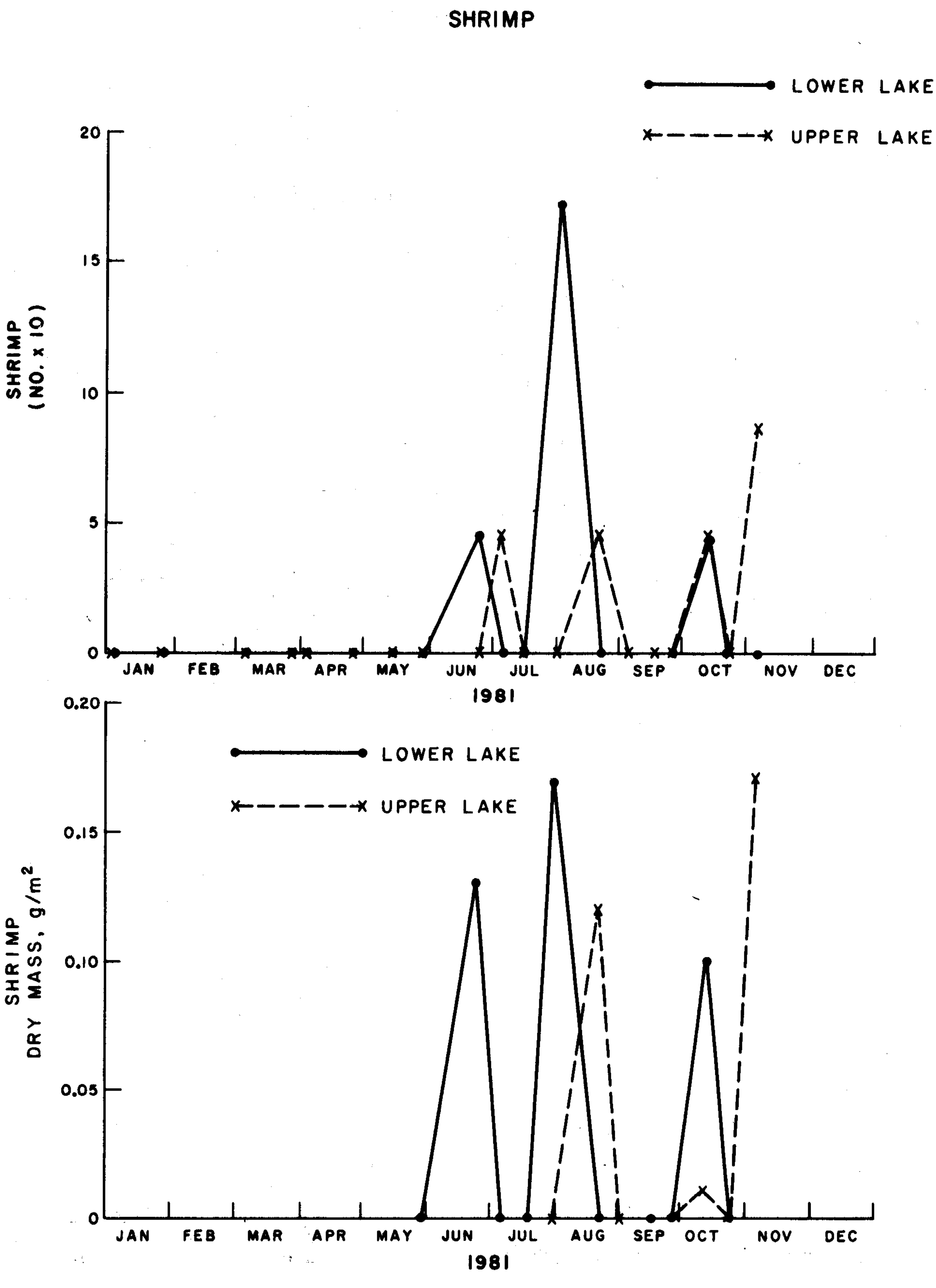


Figure 39.—Abundance and biomass of shrmp in Twin Lakes during 1981.

UPPER LAKE

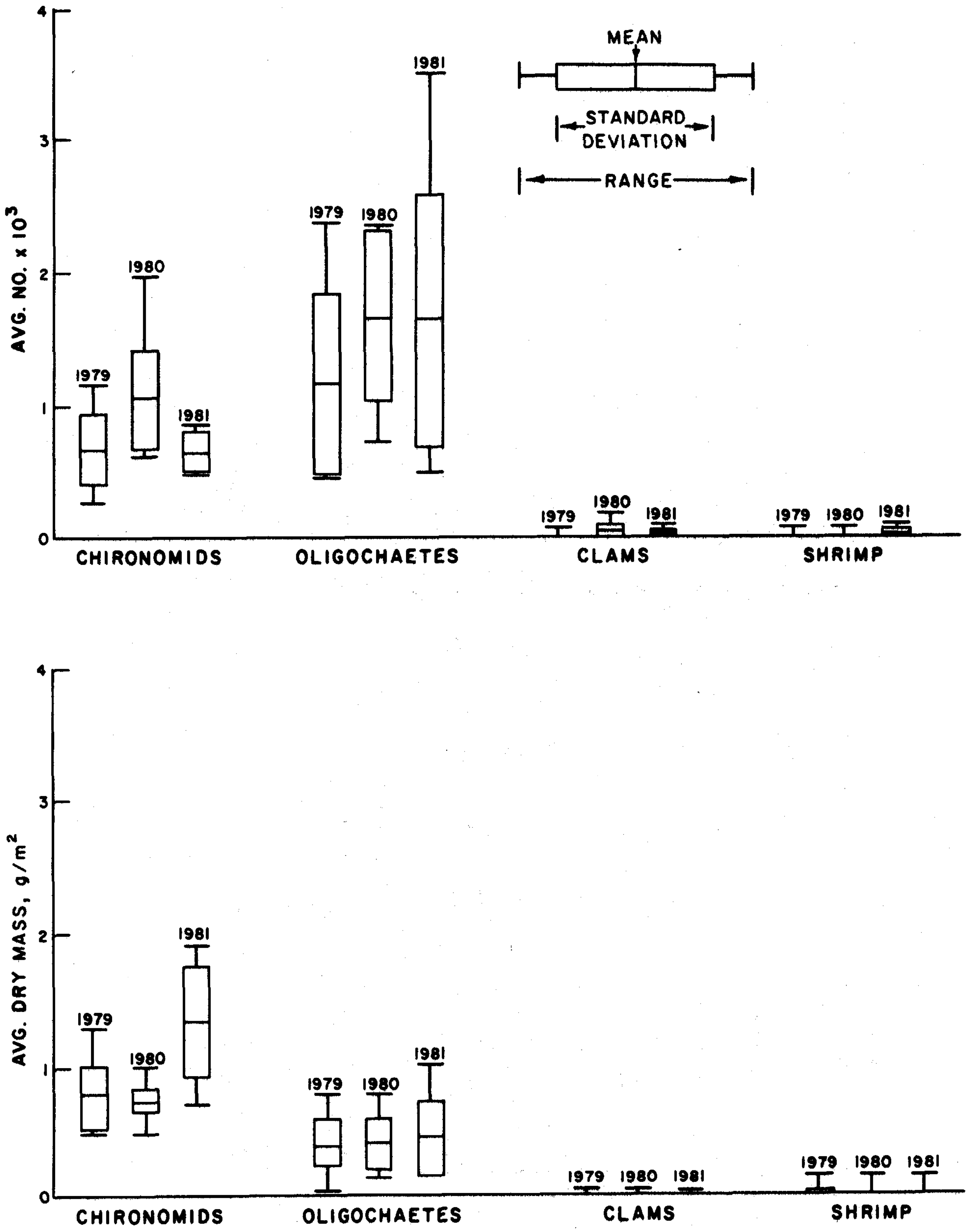


Figure 40.—Average abundance and biomass of four types of benthic organisms in upper lake, 1979-81.

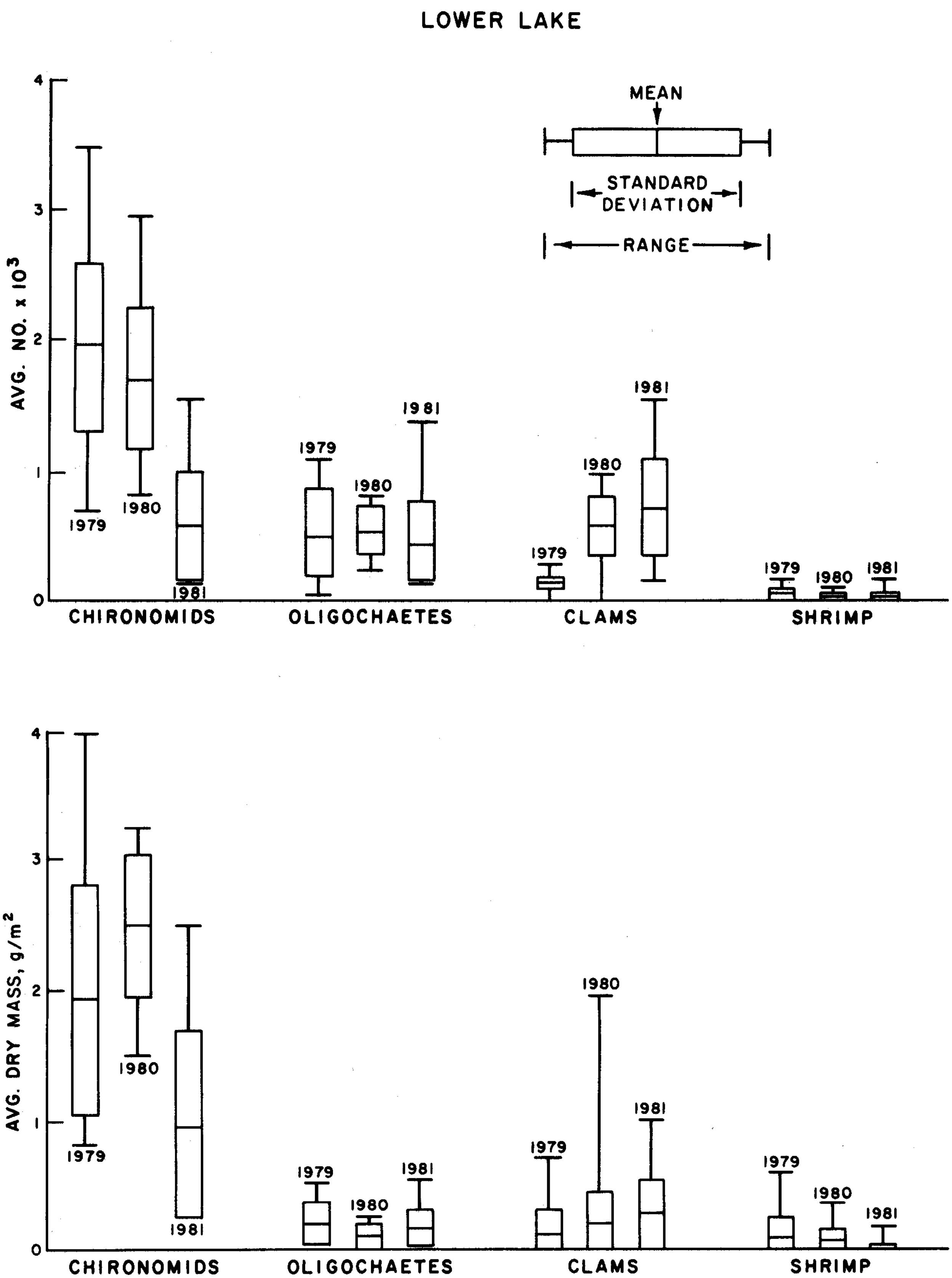


Figure 41.—Average abundance and biomass of four types of benthic organisms in lower lake, 1979-81.

Table 12 compares the average abundance of benthos, excluding mollusks, of Twin Lakes with those of other locations selected from the literature. The 1974-79 averages from Twin Lakes are also presented in this table to show how the benthos of the lakes has changed from the 1974-79 period to the present. The lower lake has generally remained in the category of a healthy, moderately productive oligotrophic lake, and the upper lake has become such a lake. However, in the 1974-76 period, the abundance of benthos in the upper lake was very low because during the later winter of 1974-75 the bottom meter or so of the hypoliminion was anaerobic. As previously discussed, this led to toxic concentrations of metals in solution at the bottom of the upper lake. The benthos of the upper lake was almost totally destroyed by this condition, and it took almost 5 years for recognizable recovery to occur. This condition has not been approached since at Twin Lakes. As the 1981 data indicate, the upper lake's benthos is in some ways more productive than that of the lower lake (figs. 40 and 41).

Mt. Elbert Forebay

The basic limnological features of Mt. Elbert Forebay are presented in Boehmke, et al., (1982) [43]. Since data in that report were collected, the forebay has been completely drained, a layer of soil removed, a CPE (chlorinated polyethylene) liner placed over the entire surface of the forebay, a 300-mm layer of soil placed over the liner, and the forebay refilled with water from Turquoise Lake by way of Mt. Elbert Conduit. This entire sequence of events took place from the fall of 1979 to the spring of 1981. Collection of limnological data from the forebay was reinstated in September 1981. In particular, we began looking for any effect on the limnology due to the CPE liner and any changes brought on by operating

Table 12. — *Comparison of abundances of benthic fauna at Twin Lakes and other selected locations*

Location	Number per square meter	Reference
Twin Lakes (upper lake, 1974-79 avg.)	548	Keefe, 1980 [15]
Twin Lakes (upper lake, 1980-81 avg.)	2492	-
Twin Lakes (lower lake, 1974-79 avg.)	2337	Keefe, 1980 [15]
Twin Lakes (lower lake, 1980-81 avg.)	1595	-
Great Slave Lake (Canada)	1603	Rawson, 1953 [36]
Seminoe Reservoir (Wyo., 4-yr. avg.)	1518	Sartoris, et al., 1981 [37]
Alcova Reservoir (Wyo., 3-yr. avg.)	4175	Sartoris, et al., 1981 [37]
Waterton Lake (Canada)	370	Rawson, 1942 [38]
Loch Levan (Scotland)	2027	Maitland, et al., 1970 [39]
Lake Pocasse (S. Dak.)	0 to 5220	Roline and LaBounty, 1980 [40]
Candlewood Lake (Conn.)	5500	Deevey, 1941 [41]
Lake Cayuga (N.Y.)	6000	Henson, 1954 [42]

the Mt. Elbert Pumped-Storage Powerplant. We were also interested as to what may have been transferred between the forebay and the lower lake. The following paragraphs are a short summary of data collected in the last quarter of 1981 and a comparison with data collected from the forebay before the liner was installed.

The maximum water surface elevation in the forebay is 2940 m above mean sea level. At this elevation, the forebay has a surface area of 109 hectares, a volume of 14 234 000 m^3, and an average depth of nearly 6 m. Figure 42 is a summary of water temperature, conductance, and chlorophyll *a* concentrations from the forebay from early September through mid-November 1981. Table 8, previously presented in this report, includes a summary of the water chemistry of the forebay during late 1981. Comparing the chemistry data from 1981 with data collected in 1978-79, the forebay was higher in total dissolved solids and lower in nutrient concentrations in 1978-79. This is because water from the forebay in 1978-79 was pumped from the lower lake and it therefore resembled Twin Lakes chemically. Water in the forebay in late 1981 mostly originated in Turquoise Lake; therefore, it resembled Turquoise water chemically.

Chlorophyll *a* concentrations ranged from 2.0 to 5.2 mg/m^3 in late 1981, and from 0.3 to 1.9 mg/m^3 in 1978 and 1979. Phytoplankton density data (fig. 43) support the chlorophyll data. Phytoplankton density was always below 300 organisms per liter on six sampling dates in 1978 and 1979, while densities ranged from a low of about 800 organisms per liter to a high of just over 17 000 organisms per liter for seven sampling dates in the last half of 1981. This means that the chlorophyll and phytoplankton data both indicate algal abundance in late 1981 to be from 3 to 20 times that found in 1978 or 1979. However, the phytoplankton species composition (tab. 13) remained similar because the forebay is dominated by *Dinobryon, Synedra,* and *Asterionella* (species of yellow brown alga and diatom). The phytoplankton species composition in the forebay is similar to that of Twin Lakes and nearby Turquoise Lake.

The abundance of zooplankton was similar in late 1981 to that found in late 1978 and 1979 (fig. 43). That is, the abundance of zooplankton was in the range of 50 to 200 individuals per liter. Species found are also similar; however, their relative abundance is not the same (tab. 13). The zooplankton fauna in late 1979, while similar to that in late 1981 in nauplii abundance, differed in that it contained a higher percentage of *Daphnia* and *Diaptomus* in 1979. Rotifers and *Cyclops* made up the greatest percentage in 1981 while *Daphnia* and *Diaptomus* were uncommon. Even though not displayed, due to their nocturnal habits, mysis shrimp were found in the forebay in 1981 but not in 1978 or 1979. They were introduced by pumping from Twin Lakes, and their presence probably influenced the species composition of the other zooplankton species. Bergersen and Maiolie, in an appended report, estimated the shrimp population in the forebay to be 35 million in late 1981.

Data on some limnological characteristics of the forebay have not yet been collected (e.g., benthos and rate of primary production); however, the forebay can be characterized as an impoundment going through biological transformation and heavily influenced by exchange of flows with Twin Lakes and inflow from Turquoise Lake. The forebay is, like the other reservoirs in the area, an oligotrophic or relative unproductive body of water. However, the forebay does seem to have a greater abundance of cladoceran zooplankton, which is true of Turquoise Lake rather than Twin Lakes. Also, mysis shrimp are very abundant in the forebay, which is true of Twin Lakes rather than Turquoise Lake. These two observations illustrate the hybrid nature of the forebay.

SUMMARY

Tables 14 and 15 summarize the more extreme values of some of the limnological data collected from Twin Lakes during 1981. A similar summary was prepared for the 1980 data and reported in LaBounty and Sartoris (1981) [21]. In the upper lake, the following parameters were, by quantitative comparison, substantially greater in 1981 than in 1980: conductivity, TKN, ammonia nitrogen, orthophosphate phosphorus and total phosphorus, primary productivity, and average chlorophyll *a* concentration. The following parameters were substantially lower in the upper lake in 1981 than in 1980: light extinction coefficient, density of chironomid larvae and, probably the one most influential factor on all the other parameters listed, the volume of inflow. Inflow volume during 1981 was significantly lower than in 1980, and this allowed greater water clarity and nutrient concentration in the upper lake, which resulted in significantly more phytoplankton in 1981. A number of parameters in the lower lake were greater in 1981 than in 1980; however, none were as significant as in the upper lake. These include windspeed, water surface temperature, average monthly temperature, dissolved oxygen concentration, some of the concentrations

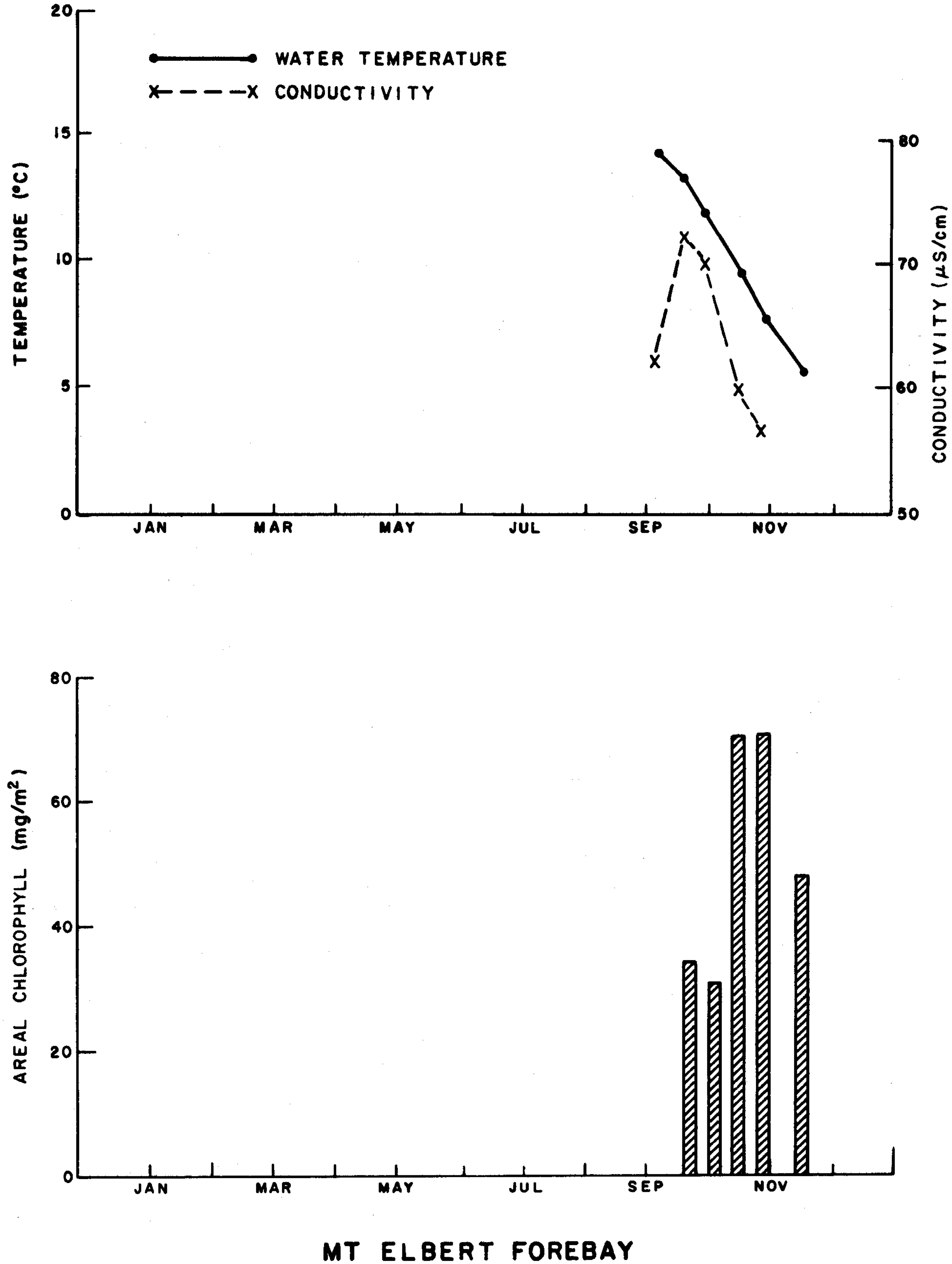


Figure 42.—Average water temperature, conductivity, and chlorophyll *a* concentrations in Mt. Elbert Forebay during 1981.

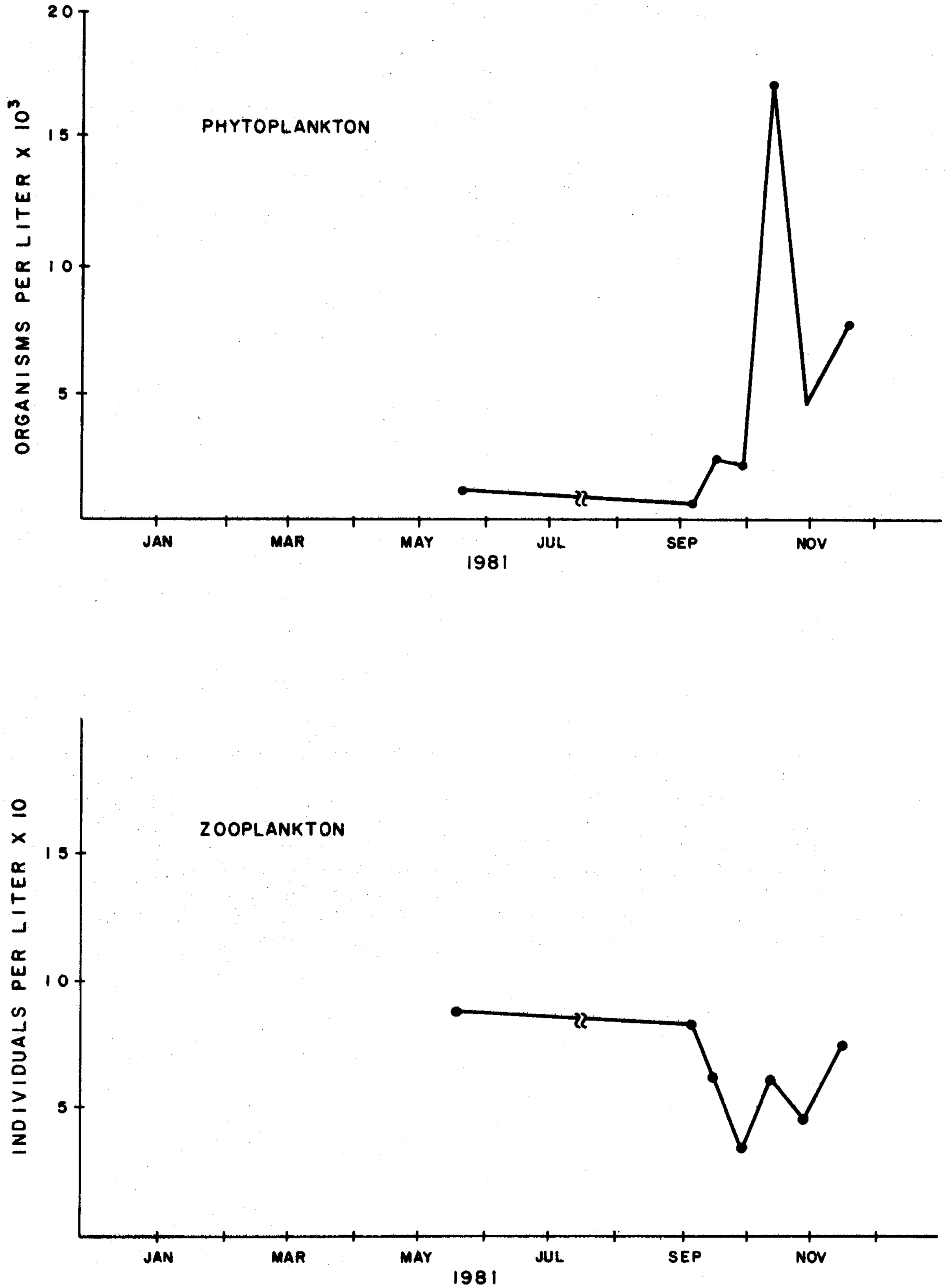


Figure 43.—Phytoplankton and zooplankton densities in Mt. Elbert Forebay during 1981.

Table 13. — *Percentages of plankton collected at Mt. Elbert Forebay during 1981*

	May 21	Sept. 1	Sept. 16	Sept. 29	Oct. 14	Oct. 28	Nov. 11	1981 average
Phytoplankton								
Asterionella	36	34	25	46	16	33	34	32
Synedra	61	29	10	8	8	9	40	24
Dinobryon	0	36	65	44	75	56	24	43
Tabellaria	2	<1	0	1	<1	1	1	1
Sphaerocystis and *Dictyosphaerium*	0	1	0	0	0	<1	<1	<1
Zooplankton								
Copepods								
Cyclops	21	8	21	29	17	15	11	17
Diaptomus	0	<1	1	2	1	1	1	1
Nauplii	43	17	20	33	5	24	17	23
Rotifers								
Keratella	1	44	31	21	20	9	13	20
Kellicottia	19	9	6	1	4	4	6	7
Polyarthra	12	12	11	10	32	23	29	18
Brachionus	0	8	7	4	19	23	18	11
Cladocerans								
Bosmina	0	<1	3	0	2	1	5	2
Daphnia	3	1	<1	0	0	0	0	1

of N-P nutrients, and phytoplankton and zooplankton densities. The lower lake's foremost difference between 1980 and 1981 was in the significant decrease in chironomid density in 1981. This has been discussed in an earlier section. In all respects, both lakes remain generally similar to what they have been since these studies began in 1973. Table 16 summarizes the general trophic parameters of Twin Lakes based on data collected during 1981. In addition, a portion of table 9-4 from Likens (1975) [44] is included in table 16 showing his trophic classifications based on the various parameters. Table 17 is a qualitative summary based on the data presented in table 16. Based on all the data collected during 1981, the Twin Lakes are categorized as oligotrophic in seven out seven limnological parameters.

Table 14. — *Extreme readings on some of the limnological data collected from lower lake during 1981*

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Ambient light[1]	g-cal/(cm²·h)	471	July	117	Sept.
Wind[1]	km/h	24.5	Aug.	1.5	Nov.
Air temp.[1]	°C	14.0	Aug.	-3.8	Oct.
Water surface temp.[1]	°C	17.1	July	0	Jan.-Apr.
Water temp.	°C	18.0	Aug.	0	Jan.-Apr.
Stratification temp. difference	°C	9.2	Aug.	0	May, Oct.-Dec.
Water temp. (monthly mean)	°C	12.7	Aug.	3.1	Jan.
Dissolved oxygen	mg/L	10.2	Feb.	1.7	Oct.
(pH)		8.3	Aug.	6.6	Oct.
Conductivity	μS/cm	92	Aug.	71	Feb.
Redox potential	mV	465	Feb.	296	July
Light extinction coefficient	m^{-1}	0.24	Apr.	0.44	Oct.
Alkalinity	mg/L	21.5	Jan.	16.5	Apr.
(TKN)	μg/L	530	June	<30	Jan., Aug.-Nov.
Nitrate nitrogen	μg/L	80	Sept.	<10	Jan., Oct.
Ammonia nitrogen	μg/L	40	Apr.	<10	Nov.
Orthophosphate phosphorus	μg/L	36	July	<1	Jan., Apr., Aug.-Nov.
Total phosphorus	μg/L	70	Apr.	<1	Jan., Aug.-Nov.
Primary productivity (areal)	mg C/(m²·d)	126.6	May	9.6	Mar.
Primary productivity	mg C/(m³·h)	1.7	Oct.	0	Oct., Nov. (below 9 m)
Chlorophyll concentration	mg/m³	7.0	Aug.	0.4	May
Avg. phytoplankton concentration	No./L	18 087	Sept.	185	Feb.
Avg. zooplankton concentration	No./L	153	June	11	Mar.
Density of chironomid larvae	No./m²	1 471	May	173	July
Density of oligochaetes	No./m²	974	May	173	July
Density of pea clams	No./m²	1 536	Apr.	129	Feb.

[1] Daily average.

Table 15. — *Extreme readings on some of the limnological data collected from upper lake during 1981*

Parameter	Units	Maximum	Month found	Minimum	Month found
Water temp.	°C	18.0	Aug.	0	Jan.-Apr.
Stratification temp. difference	°C	11.0	Aug.	0	Jan.-May, Oct.-Nov.
Water temp. (monthly mean)	°C	10.6	Aug.	3.7	Feb.
Dissolved oxygen	mg/L	10.1	Mar.	2.1	Apr., Sept.
(pH)		8.3	Aug.	6.5	Mar., Oct.
Conductivity	μS/cm	102	Apr.	69	July
Redox potential	mV	496	Apr.	266	June
Inflow volume	$m^3 \times 10^7$	3.377	June	0.103	Feb.
Light extinction coefficient	m^{-1}	0.59	June	0.29	Apr.
Alkalinity	mg/L	24	Feb.	13	June
(TKN)	μg/L	930	Apr.	<10	Jan.
Nitrate nitrogen	μg/L	110	Mar.	<10	Apr.
Ammonia nitrogen	μg/L	170	Apr.	<10	Apr., July, Sept.
Orthophosphate phosphorus	μg/L	25	Apr.	<1	Jan.-Feb., Apr., Aug.-Nov.
Total phosphorus	μg/L	31	Mar.	<1	Jan.-Feb., Apr., Aug.-Nov.
Primary productivity (areal)	mg $C/(m^2 \cdot d)$	103.6	May	8.4	Mar.
Primary productivity	mg $C/(m^3 \cdot h)$	1.5	Aug.	0	June-Oct. (below 9 m)
Chlorophyll concentration	mg/m^3	18.8	Sept.	0.6	Mar.
Avg. phytoplankton concentration	No./L	4871	Sept.	705	Sept.
Avg. zooplankton concentration	No./L	55	Aug.	7	Mar.
Density of chironomid larvae	$No./m^2$	822	Aug.	519	July
Density of oligochaetes	$No./m^2$	2900	July	432	July
Density of pea clams	$No./m^2$	86	Apr.	0	Feb.-Dec.

Table 16. — *Some general limnological characteristics of Twin Lakes compared to parameters by Likens (1975) [44] to categorize trophic status*

Lake	Mean primary productivity, mg C/(m²·d)	Total organic carbon, mg/L	Chlorophyll *a*, mg/m³	Dominant phytoplankton	Light extinction coeff., m^{-1}	Total P, µg/L	Total N, µg/L
Lower lake (1981)	67.6	[1]1.6-2.1	0.4-7.0	Chrysophyceae	0.24-0.44	<1-70	<30-530
Upper lake (1981)	47.3	[1]1.4-1.7	0.6-18.8	Bacillariophyceae	0.29-0.59	<1-31	<30-930
Ultra-oligotrophic	<50		0.1-0.5	Chrysophyceae, cryptophyceae	0.03-0.8	<1-5	<1-250
Oligotrophic	50-300	<1-3	0.03-3	Dinophyceae, Bacillariophyceae	0.05-1.0		
Oligo-mesotrophic						5-10	250-600
Mesotrophic	250-1000	<1-5	2-15		0.1-2.0		
Mesoeutrophic						10-30	500-1100
Eutrophic	>1000	5-30	10-500		0.5-4.0		

[1] As measured in 1975

Table 17. — *Categorization of trophic status of Twin Lakes based on data in table 16*

Parameter	Upper lake	Lower lake
Primary productivity	Oligotrophic	Oligotrophic
Chlorophyll *a*	Oligotrophic[1]	Oligotrophic[1]
Dominant phytoplankton	Oligotrophic	Oligotrophic
Light extinction coefficient	Oligotrophic	Oligotrophic
Total organic carbon	Oligotrophic	Oligotrophic
Total P	Oligotrophic[1]	Oligotrophic[1]
Total N	Oligotrophic[1]	Oligotrophic[1]

[1] Some values of this parameter measured during 1981 categorize Twin Lakes as meso or even eutrophic (highly productive). These values are random in time and location in the water column. The average or general value for these parameters place Twin Lakes in the oligotrophic category.

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Note: From Nov. 1979 to May 1981, the Bureau of Reclamation was known as the Water and Power Resources Service; consider the names synonymous in this Bibliography.

APPENDIX A

TWIN LAKES INVESTIGATIONS—ENTRAINMENT PHASE I—TESTING

1981 Annual Progress Report

Submitted by:

Eric P. Bergersen
Principal Investigator

and

Melo A. Maiolie
Research Associate

Colorado Cooperative Fishery Research Unit
Fort Collins, Colorado

USBR Contract #7-07-83-V0700

PREFACE

The Colorado Cooperative Fishery Research Unit is currently involved in a two-phase study to assess the environmental impacts of the Mt. Elbert Pumped-Storage Powerplant. The first phase of the study, which extended from May 1981 to May 1982, was primarily concerned with the development of equipment to effectively monitor fish and mysis shrimp entrained in the powerplant. Different equipment was developed for use in both the forebay and tailrace enabling sampling to be conducted during both generation and pumping cycles. This report is a summary description of equipment fabricated and methods to be used in monitoring entrainment. The second phase of the study, from May 1982 to May 1983, will be to use this equipment and routinely sample powerplant discharges. In addition to reports on the equipment built for the entrainment studies, two other chapters have been added; one on the pattern of lake currents during generation, and an update of mysis shrimp densities in Twin Lakes and the forebay.

Chapter 1
Tailrace Sampling Barge

INTRODUCTION

One important aspect of evaluating fish (brown, lake, and rainbow trout and white and longnose suckers) and the mysis shrimp mortality induced by the Mt. Elbert Pumped-Storage Powerplant involves the netting of organisms passed through the powerplant during generation. Because of the uniqueness of the powerplant tailrace, fish and mysis sampling devices needed to be designed, built, tested, and evaluated before the powerplant impacts could be determined. The tailrace sampling barge was built during the summer of 1981 to serve as a movable apparatus which could sample powerplant outflows at various depths and positions in the tailrace.

DESCRIPTION

Two U.S. Army bridge barges, 9 m long by 2 m wide by 1 m deep, served as pontoons for the sampling barge (figs. A-1 and A-2). A 7-m-

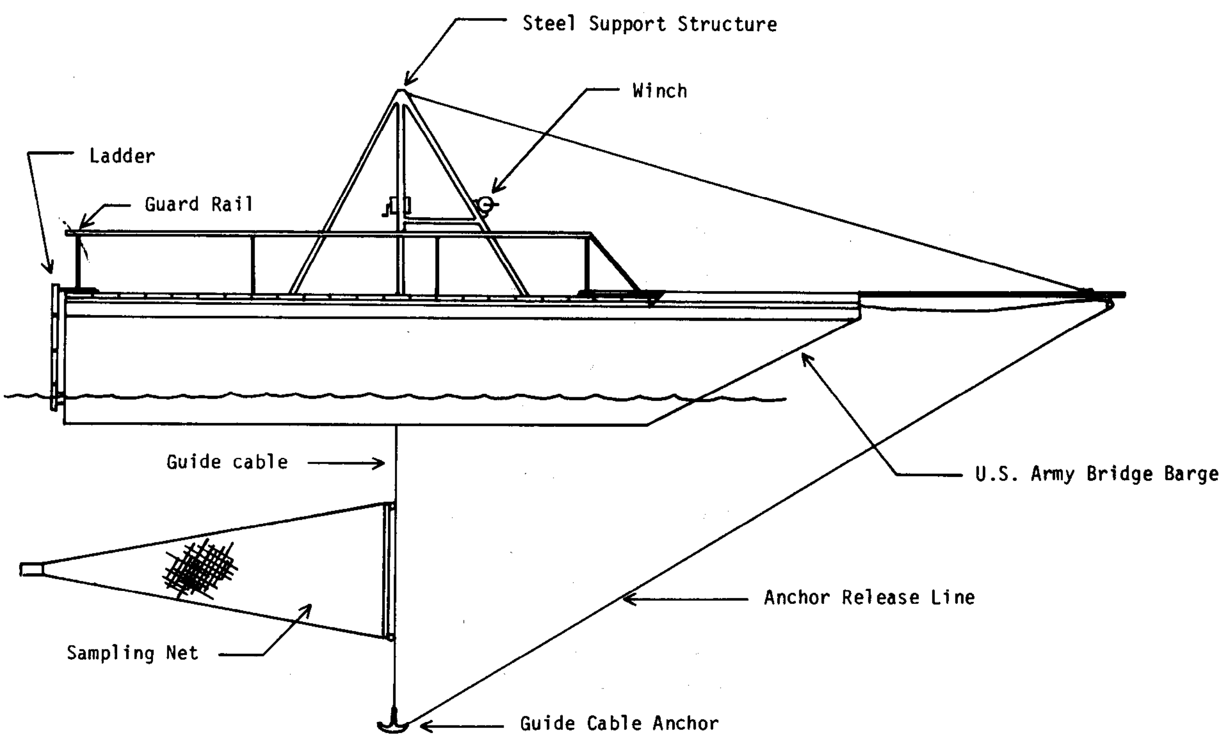

Figure A-1.—Starboard side view of tailrace sampling barge with sampling net lowered. Barge is used to sample outflow from the Mt. Elbert Powerplant during generation.

square deck was built of rough-cut lumber (2 by 12 cm) and steel angle iron (5 cm by 5 cm by 7 m) across the top of the pontoons. A 2.4- by 3.6-m opening was left in the center of the deck through which nets could be raised and lowered. A steel support structure, built of 5- by 5-cm angle iron, was bolted to the deck to allow the nets to be raised completely out of the water. Four winches were attached to the steel support structure; two to hold the heavy 6-mm-diameter guide cables, one to raise the net, and one to lower the net. A fifth winch was attached to the bow mast for release of the guide cable anchor. Cross members of 6-mm-diameter steel cable were placed under the deck and between the pontoons to add rigidity to the structure. Other fixtures on the boat include a guard rail, a ladder on the stern, and four large boat cleats.

OPERATION AND TESTING

During the fall of 1981 the operation of the sampling barge was tested by the following procedure. The barge was towed by boat into the tailrace, and ropes connected the barge to the floatline deadmen and the powerplant to maintain the barge's position. The guide cable anchor was then lowered and hooked onto the attachment cable; the attchment cable had been previously installed when the tailrace was constructed. Nets were then raised and lowered on the guide cables. The nets for the fish were 2 m square with 25-mm bar mesh, and 2 by 1 m with 12-mm bar mesh for the mysis shrimp.

The barge was quite functional and operation should be relatively easy for two people. The procedure described will be used to sample powerplant outflow during the open water periods of 1982.

Chapter 2
Forebay Net

INTRODUCTION

A second important aspect of evaluating the fish and mysis shrimp mortality induced by the Mt. Elbert Pumped-Storage Powerplant involves the netting of organisms passed through the powerplant during pumping. A sampling catwalk, net frame, and winch stanchions were built by the Bureau of Reclamation to sample powerplant outflows in the forebay. This equipment was assembled into a sampling apparatus and tested during the pump cycle.

DESCRIPTION

The forebay sampling apparatus consists of a 27.4- by 9.1-m floating catwalk supporting two

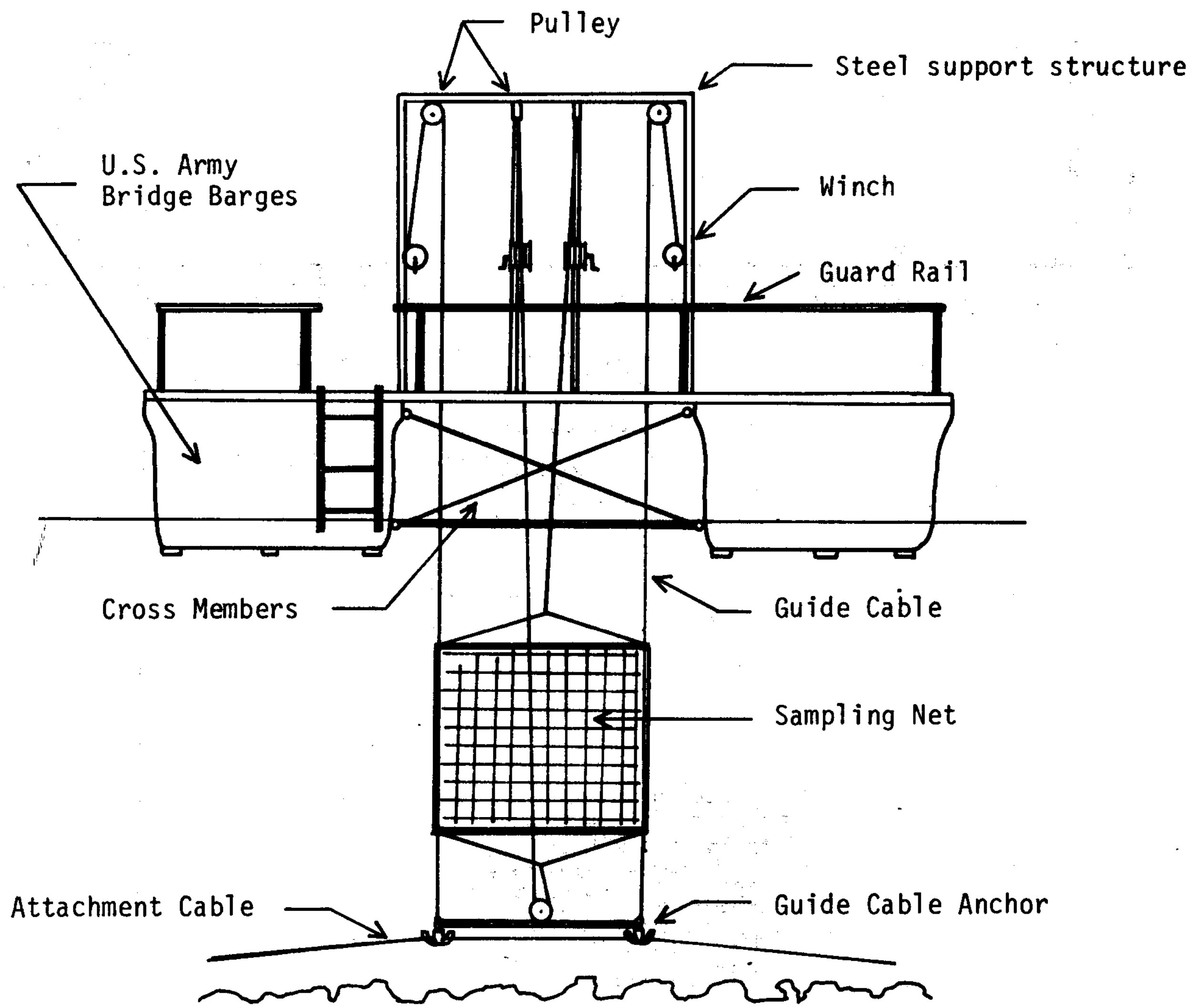

Figure A-2.—Stern view of tailrace sampling barge with sampling net lowered.

movable winch stanchions which raise and lower the net, which is 3.7 by 7.3 m with a 25-mm bar mesh (fig. A-3). A funnel-like throat with a 450-mm-diameter opening inside a PVC (polyvinyl chloride) pipe frame (1.2 by 1.2 by 1.8 m) was sewn into the cod end of the net to keep fish and fish pieces from falling out of the net when it is raised.

OPERATION AND TESTING

The catwalk was positioned over the forebay trashrack and held in place by counterweighted cables. Winch stanchions were clamped into place and the net and frame attached to the winch cables. To set the net, the cod end was first stretched away from the frame to ensure no tangles existed. The net was then lowered by the winches until the frame rested directly on the trashrack. After sampling, the net was winched up and the trap at the rear of the net opened, inspected, and contents removed. The net frame was then secured to the catwalk with ropes to be ready for the next sampling.

Setting the forebay net was best accomplished by two people, one operating each winch. Emptying the trap was somewhat awkward since it had to be accomplished from a small boat. No problems with the net tangling were noted and the net appeared satisfactory for sampling. Some sections of the catwalk tilted severely under the weight of the winch stanchions and will require further modifications.

Chapter 3
Fish Length Regressions

INTRODUCTION

Fish pieces will undoubtedly be found in samples of powerplant outflow. It will be important to

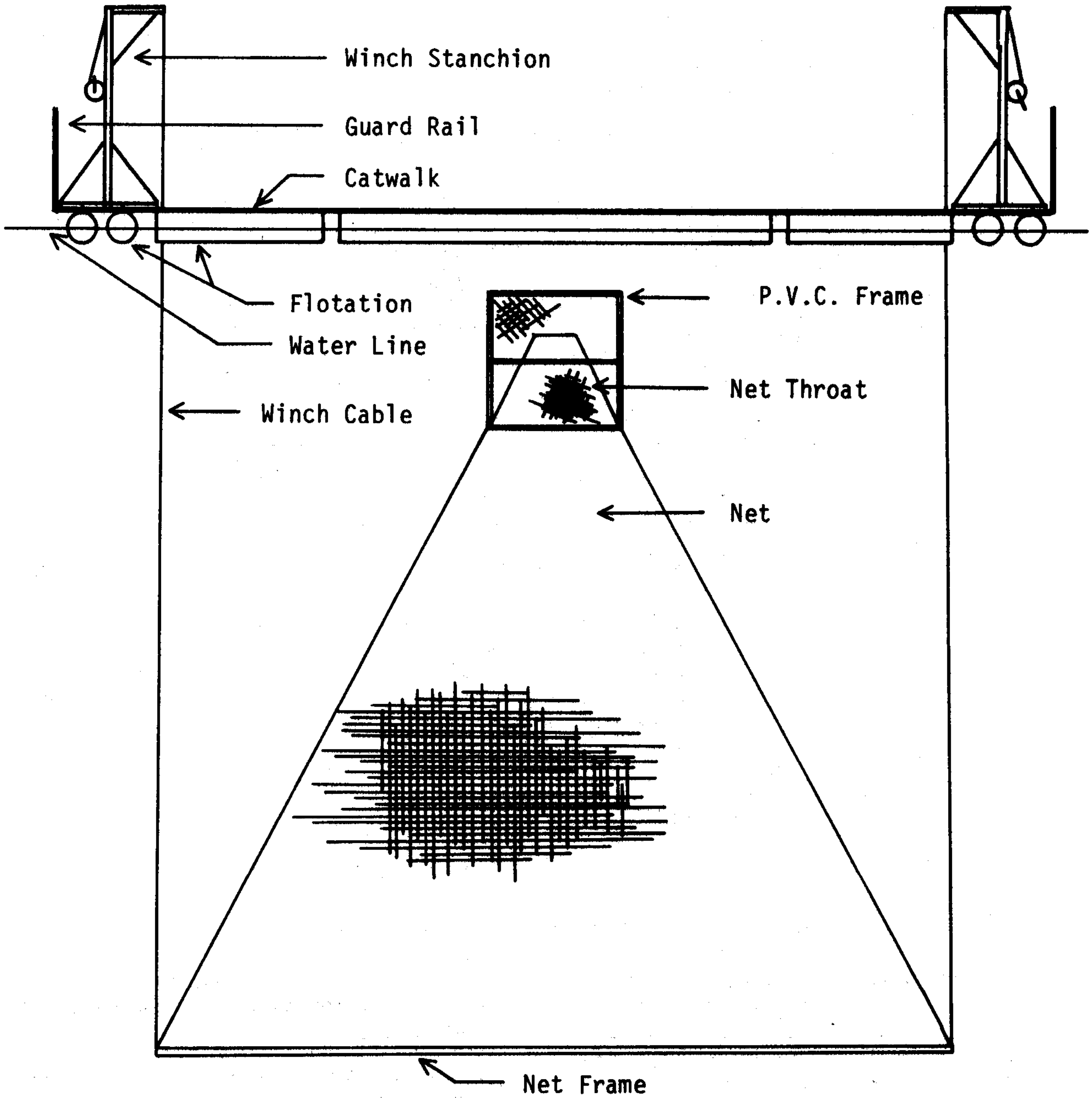

Figure A-3.—Side view of forebay sampling apparatus with net lowered. Apparatus is used to sample outflow from the powerplant during the pump-back cycle.

estimate the total lengths of the fish from these pieces so that studies of differential mortality based on size, size class entrainment variability, and size to weight conversions can be made. To accomplish this estimation, segments of a fish's body are measured and compared to its total length and appropriate regression relationships generated. This will allow us to estimate fish lengths when only pieces are recovered in the nets.

METHODS AND RESULTS

Five length measurements were made on 23 white suckers, 24 lake trout, 7 rainbow trout, and 7 longnose suckers. Fish were taken from Twin Lakes in gill nets by the Colorado Division of Wildlife. Length measurements included total length, head length, anus to fork length, front of dorsal fin to fork length, and dorsal fin length (fig. A-4). A regression line was calculated for

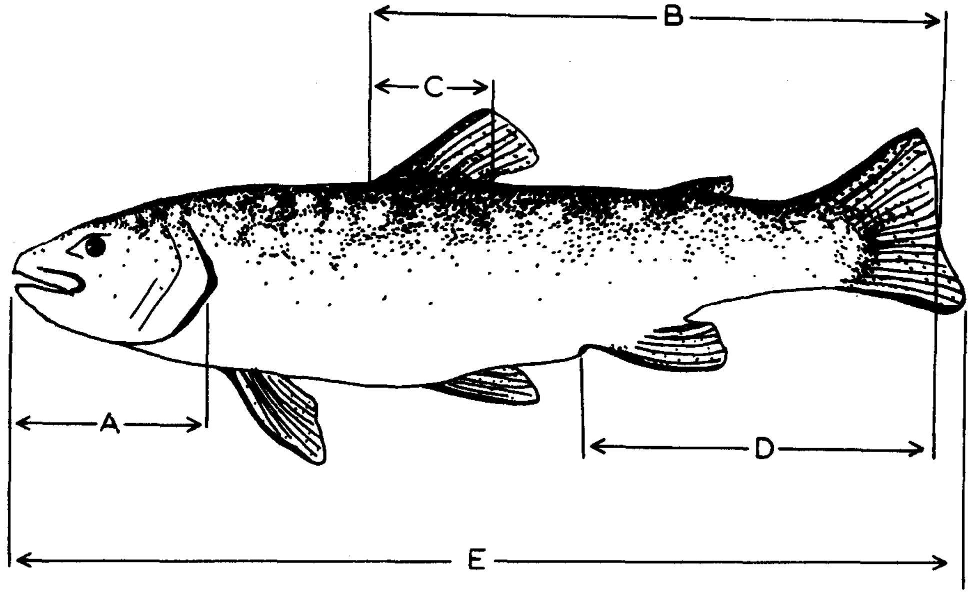

Figure A-4.—Length measurements taken on various fish species from Twin Lakes. A = head length, B = front of dorsal fin to tail fork length, C = dorsal fin length, D = anus to fork length, and E = total length.

each of the latter four lengths against the total length (figs. A-5 through A-12). Equations for calculating the total length from a given segment of a fish's body were calculated by the least squares method and are included on each figure.

DISCUSSION

Additional length data are still needed for rainbows, longnose suckers, brown trout, small lake trout, and small rainbows. More fish should be available during the summer of 1982 enabling us to complete the needed regressions.

Chapter 4
Lake Currents During Generation

INTRODUCTION

Strong under-ice currents produced by the Mt. Elbert Pumped-Storage Powerplant could affect both the physical and biological characteristics of the Twin Lakes system. Such currents could erode or pit the ice sheet, resuspend sediments, and/or influence the distribution and abundance of various organisms. Thus, it is necessary to study under-ice currents during both the pre- and postoperational phases of our investigations.

METHODS

An ink tracing technique was developed in April 1980 to measure the speed and direction of currents under the ice sheet. A 2-m probe was constructed of a 19-mm-diameter polyvinyl chloride pipe, and a 100-mm measuring bar was attached to it's lower end. A Quanterron 10-mL oral syringe was fitted into the probe and a cap with an 0.8-mm hole in the tip was placed over the end of the syringe (fig. A-13).

When the probe was lowered through a 150-mm-diameter hole cut through the ice, a plume of white ink passively streamed from the syringe tip. This plume was then disrupted by moving the probe several millimeters to one side. The break in the ink trail was timed as it moved the length of the measuring bar, and three velocity measurements were averaged at each location. Current direction was measured with a sextant in terms of degrees from a known point on shore. The sextant was also used to triangulate the location of each current measurement station. The methodology for this method is described in Bergersen and Maiolie (1981)[1].

On February 20, 1982, a powerplant generation was conducted from 0200 to 1615 hours which passed 4.25 million cubic meters of water through the Mt. Elbert Powerplant. Between 0737 and 1507 hours, the speed and direction of lake currents were measured using the ink-tracing

[1] Bergersen, E.P., and M. Maiolie, "Twin Lakes Studies —1980 Annual Progress Report," USBR contract No. 7-07-83-V0700, 1981.

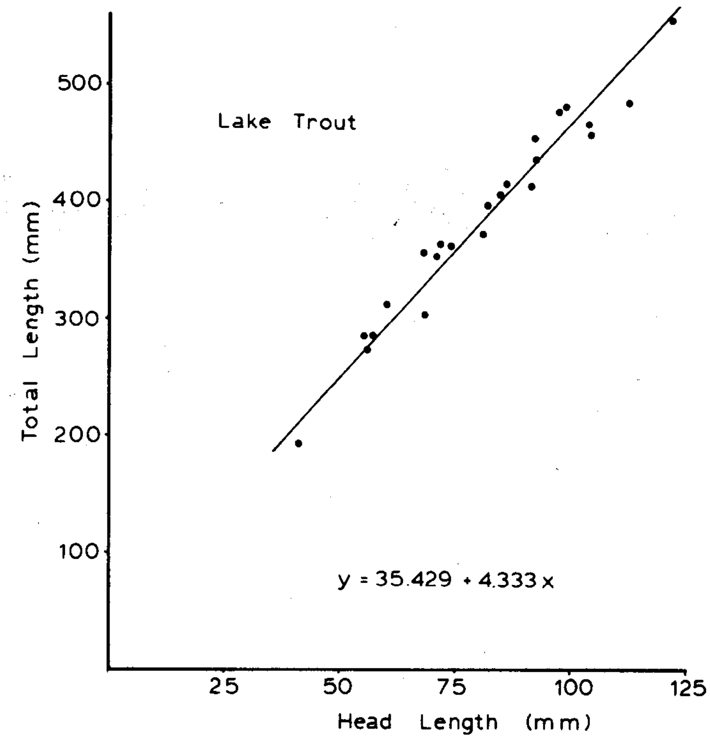

Figure A-5.—Relationship between lake trout head size and total length.

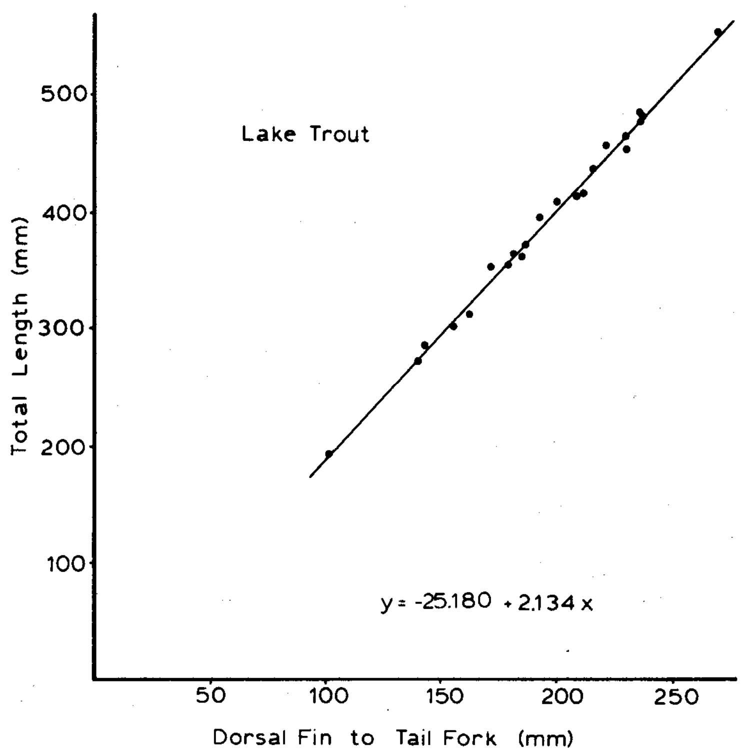

Figure A-6.—Relationship between lake trout dorsal fin to tail fork length and total length.

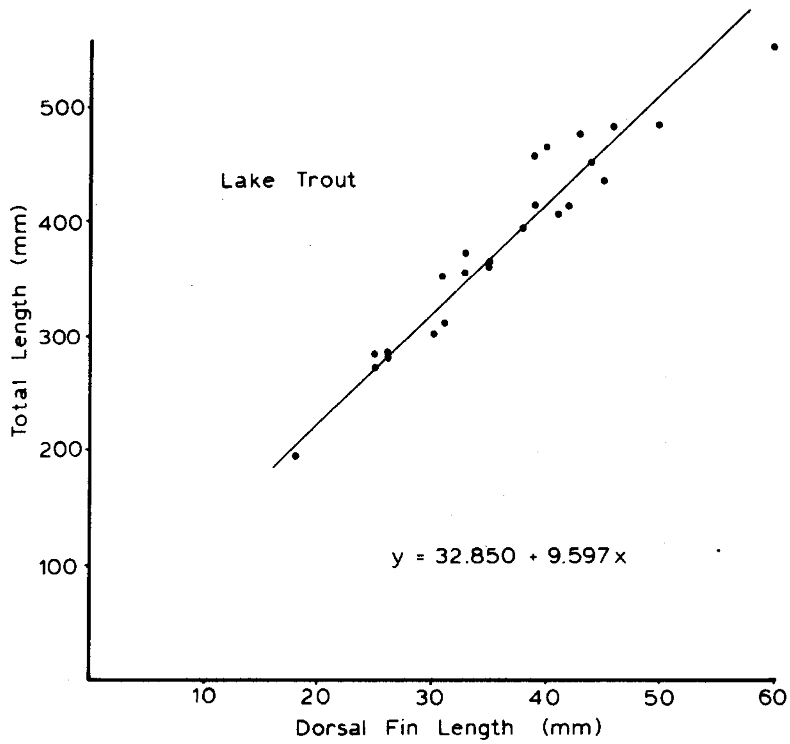

Figure A-7.—Relationship between lake trout dorsal fin length and total length.

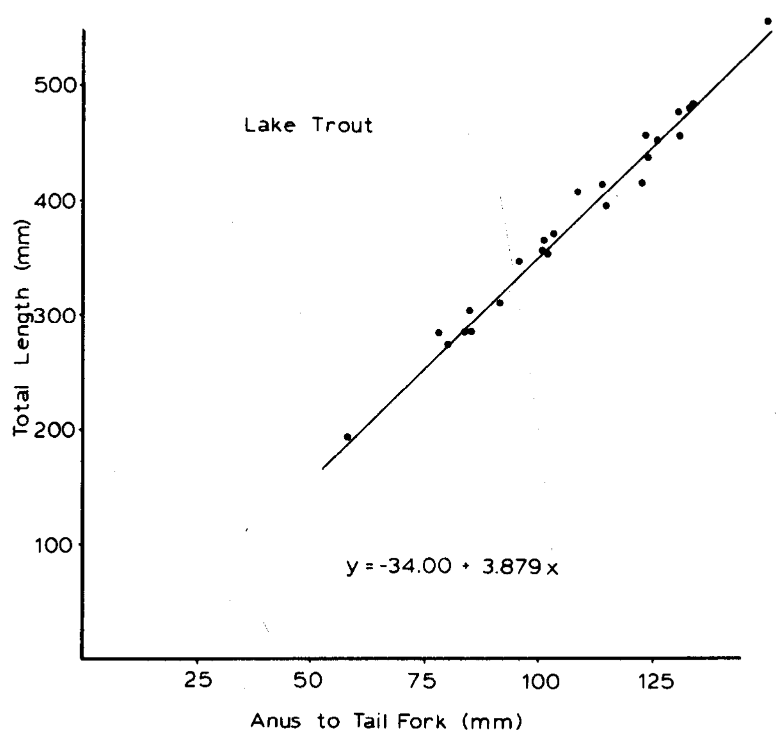

Figure A-8.—Relationship between lake trout anus to tail fork length and total length.

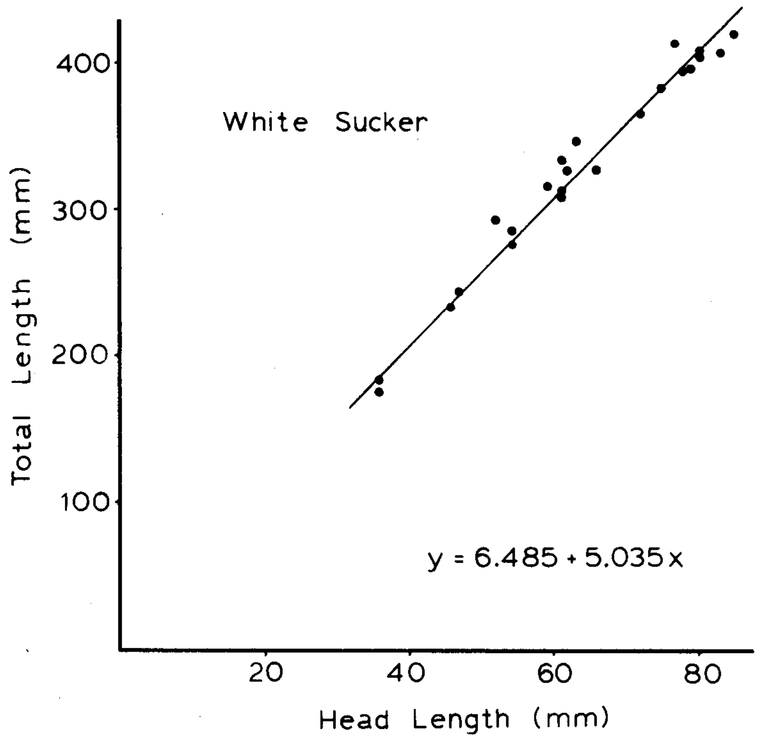

Figure A-9.—Relationship between white sucker head size and total length.

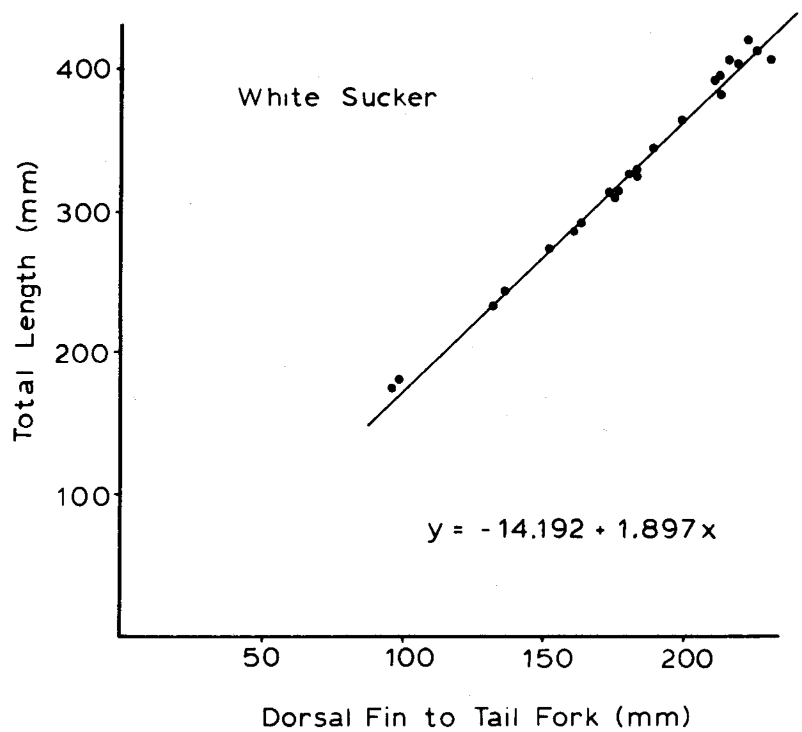

Figure A-10.—Relationship between white sucker dorsal fin to tail fork length and total length.

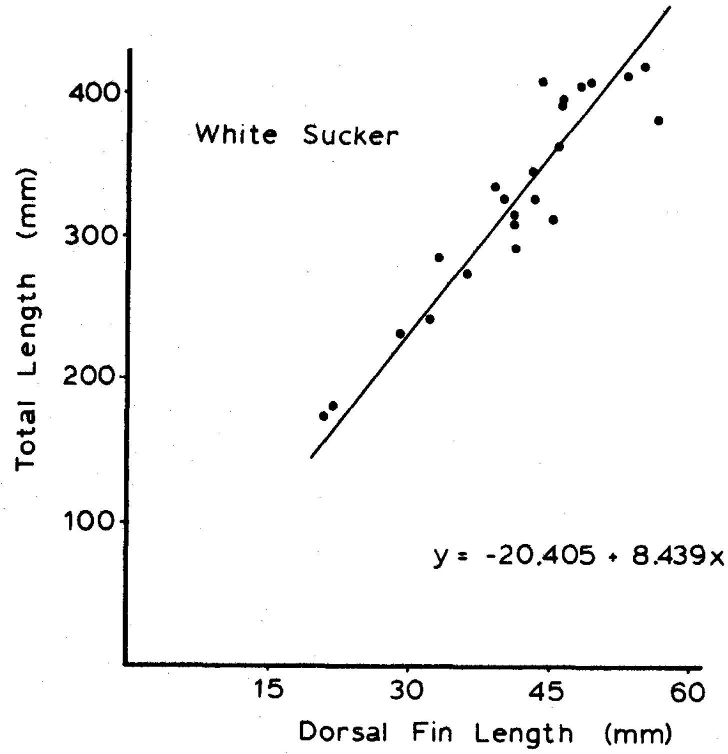

Figure A-11.—Relationship between white sucker dorsal fin length and total length.

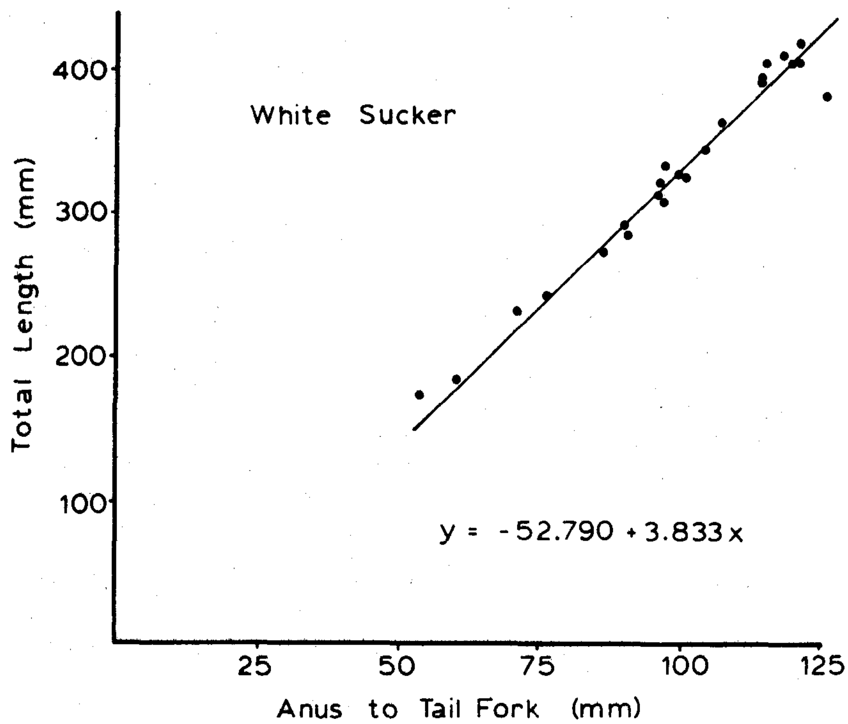

Figure A-12.—Relationship between white sucker anus to tail fork length and total length.

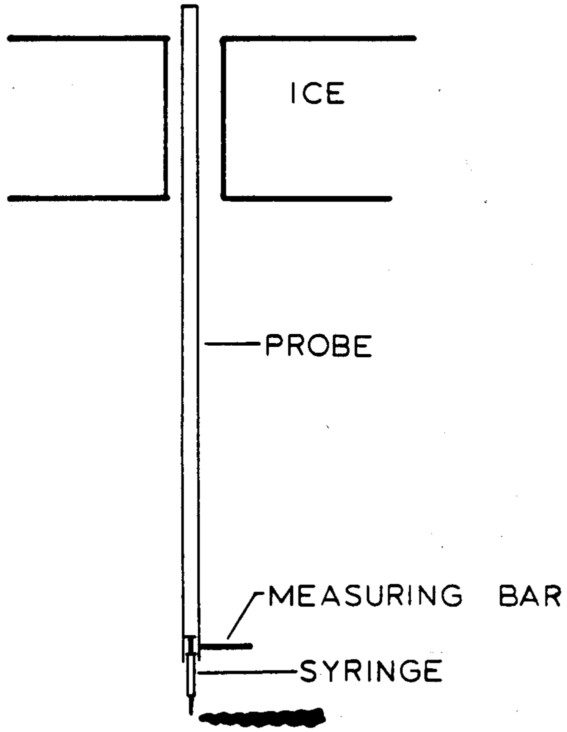

Figure A-13.—Probe used to measure under-ice currents.

technique. Current speed and direction were measured at 45 locations on the lower lake. Ice thicknesses were measured at 37 locations between 1535 and 1635 hours, after most of the generation had occurred, to determine the current's effect on the ice sheet.

RESULTS

A large, oval, counterclockwise gyre was found which covered the western two-thirds of the lower lake (fig. A-14). Current velocities within this gyre ranged from 40 to 474 cm/min. On the eastern one-third of the lake, several small gyres were found with velocities ranging from 13 to 79 cm/min. Ice thicknesses ranged from 34 to 58 cm. The thinnest ice was associated with high current velocities; however, most of the ice varied little in thickness (fig. A-15).

DISCUSSION

Lake currents in February 1981, before powerplant operation began, were characterized by numerous small gyres with current speeds averaging 32 cm/min (fig. A-16). This contrasts markedly with the currents observed during generation, where the pattern was dominated by one large gyre with an average lake current speed of 88 cm/min. Thus, the powerplant appears responsible for the currents observed in the large gyre. It is also interesting to note that the powerplant induced gyre was delineated on it's eastern side by the 2778-m contour (fig. A-14). This is the contour along which the predominantly flat bottom of the deepest part of the lake begins to slope upward toward the eastern end of the lake. the velocities and patterns of current on the eastern one-third of the lake were not greatly different from preoperational currents.

Operation of the powerplant circulated about two-thirds of the lake, which appeared to include all of the deep basin. This induced water flow will likely carry with it the mysis shrimp, particularly when generation is conducted before sunrise or after sunset. Thus, shrimp will continually be circulated into the area in front of the powerplant where entrainment during pumping is likely. Pumping mortality may therefore affect the whole of the shrimp population, not just those in the vicinity of the powerplant.

Ice thicknesses were measured to see if the 14-hour generation pitted or eroded the ice sheet. Open water, broken ice, and ice of reduced thickness were observed in the area directly in front of the powerplant. However, the bulk of the ice sheet remained relatively constant in thickness, and no areas dangerous to vehicular travel were noted. It should be noted; however, that our measurements were made on a rather isolated generation and the effects of daily pump-generation cycles have yet to be determined.

Chapter 5
Mysis Shrimp Population Estimates

INTRODUCTION

Operation of the Mt. Elbert Pumped-Storage Powerplant will entrain mysis shrimp, and it is important to document any impact the powerplant may have on the shrimp population because they are a principal food of the lake trout *(Salvelinus namaycush)*. Previously, a photographic method was developed to estimate shrimp densities, which proved to be more accurate and less labor intensive than other methods. Phototrawling for shrimp was principally conducted directly in front of the powerplant during 1980. During 1981, we attempted to develop whole-lake shrimp population estimates instead of confining estimates to the area in front of the powerplant. In so doing, we expected to be able to note changes in the

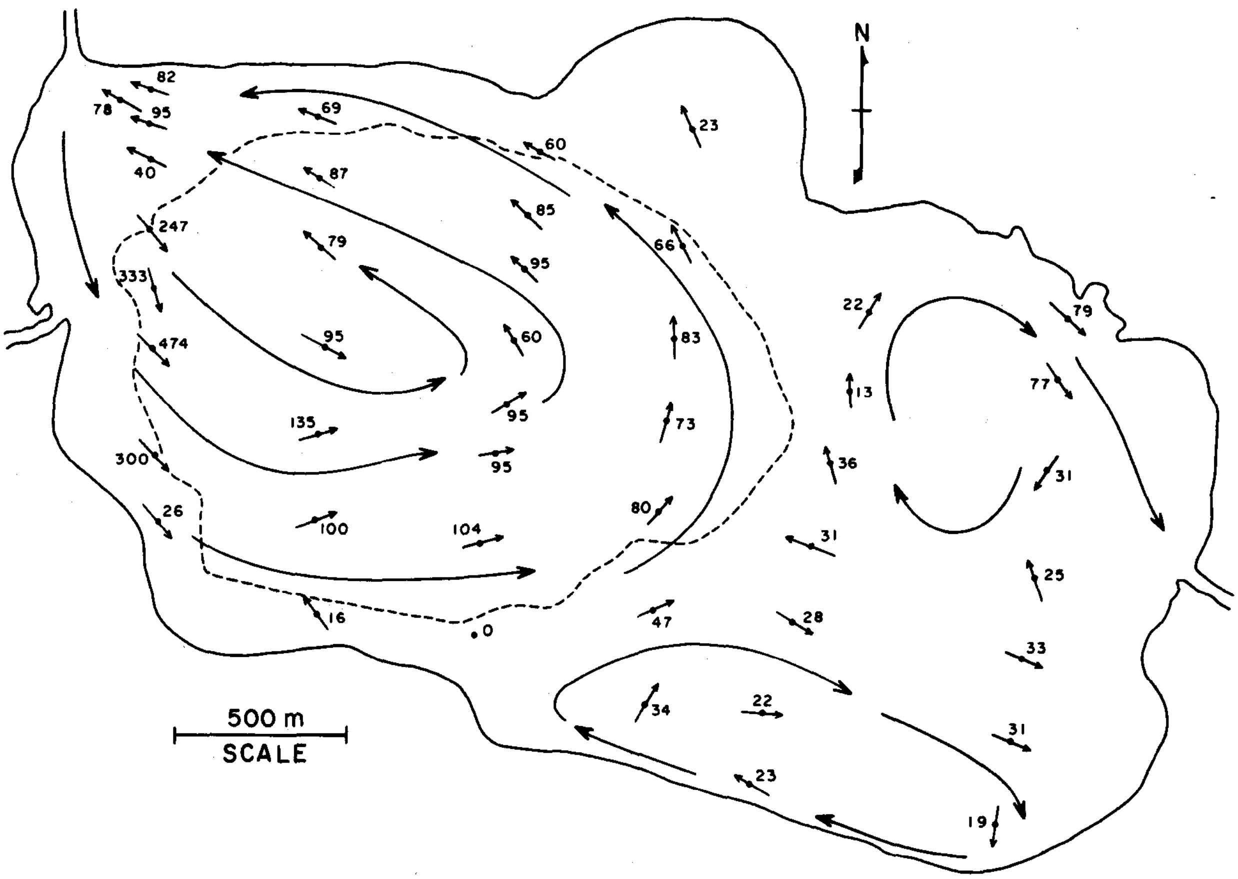

Figure A-14.—Under-ice currents in lower lake on Feb. 20, 1982. Current speeds shown are given in cm/min. Flow direction lines, fitted by inspection, were added for clarity. Dotted line represents the 2778-m contour.

shrimp population in both lakes as well as to monitor the developing population in the forebay.

METHODS

Equipment and Use

A bottom sled trawl (1.5 m long, 1.3 m wide, and 0.7 m high) made of 19-mm-diameter aluminum tubing was used in this study (fig. A-17). Skids (150-mm wide by 1.5 m long) flanked each side of the trawl and prevented the trawl from sinking to the bottom. A Farallon oceanic strobe (model 2001) was mounted over the net mouth. A Canon Fl camera, with a 35-mm lens and autowinder, was enclosed in a waterproof housing and suspended in front of the trawl. Exposures covering 0.083 m^2 were taken directly between the trawl skids. Camera speed was set at 1/60 of a second at f-13.5 with the film plane 560 mm above the lake bottom. A remote shutter cable, 75 m long, activated the camera and enabled an entire role of film to be exposed without servicing the camera. Kodacolor II, 100 ASA, 36-exposure film was used.

General Oceanics Inc. digital flowmeters (models 2030 and 2035), in conjunction with a stopwatch, measured boat speed and distance trawled. Depths were measured at the beginning and end of each trawl using a Lowrance depth-finder or the calibrated tow cable.

An outboard powered boat was used to tow the phototrawl by a 75-m long, 2.4-mm-diameter steel cable. Trawls lasted about 7 minutes with 36 pictures being taken at 12-second intervals. Four trawls were taken in the forebay, four in the upper lake, and five in the lower lake. Positions for each trawl were chosen by stratified random sampling (fig. A-18). Modification of the chosen position had to be made in the forebay to avoid the forming ice sheets (fig. A-19). Trawl speeds ranged from 0.68 to 0.98 m/sec. All trawls were conducted between 0800 and 1600 hours. Sampling was conducted at Twin Lakes on October 28 and 29 and in the forebay on December 4, 1981.

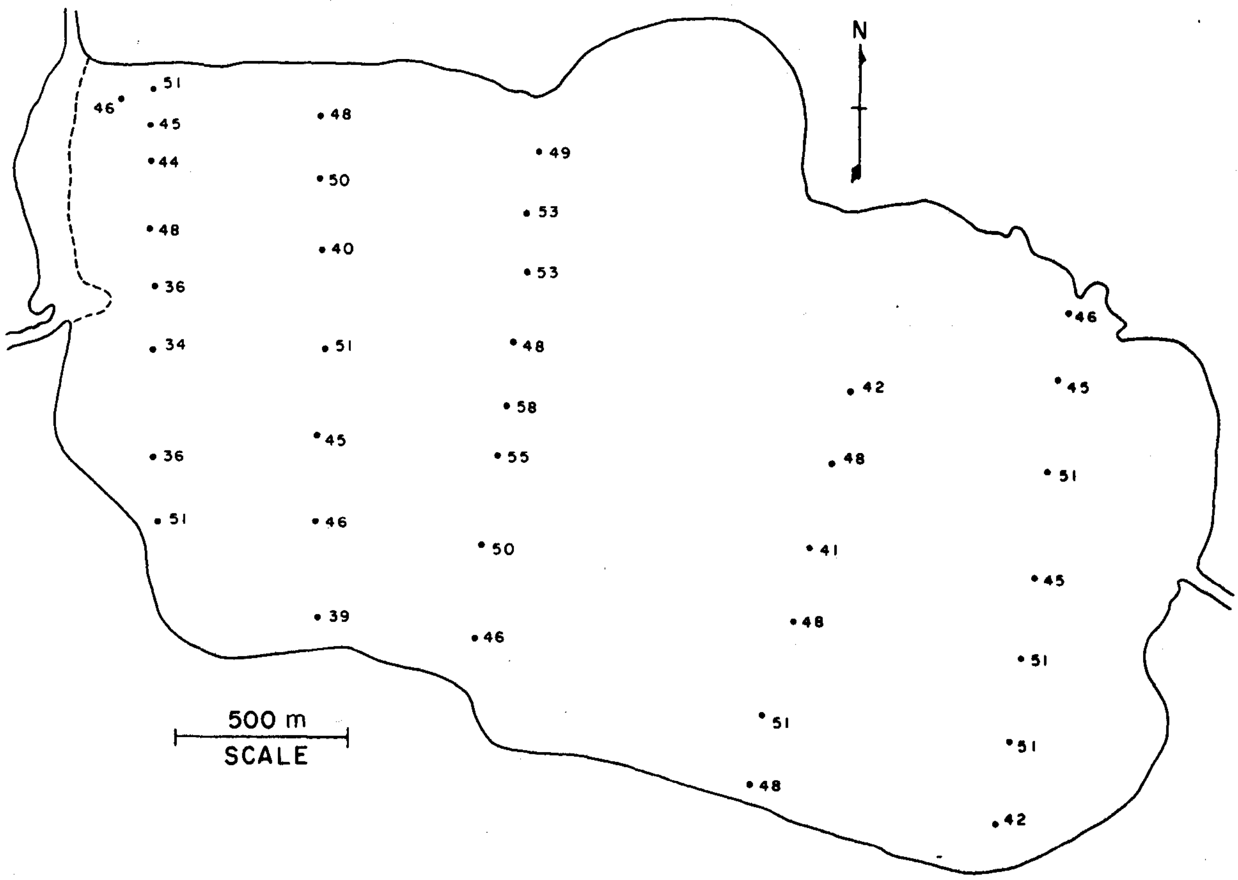

Figure A-15.—Ice thickness in centimeters of lower lake on Feb. 20, 1982. Dotted line indicates area of open water.

Statistical Analysis

The mysis shrimp were found to be clumped on the bottom of Twin Lakes and the forebay. Their distribution was not found to be significantly different from a negative binomial distribution (Bergersen and Maiolie, see footnote [1]); thus, statistical analyses which assumes normality could not be used on the raw data. To accommodate this distribution, $\log_e$ transformations were applied to the data by the formula

$$y = \log_e (x + 1) \qquad (1)$$

where x equals the number of shrimp seen in each photograph. Statistical analyses were then applied to the transformed data, y. Confidence intervals were found for the transformed data based on the Z-distribution. T-tests were also conducted on the transformed data to note whether significant differences in shrimp densities occurred between the three bodies of water and to note if shrimp densities in front of the powerplant differed significantly from the rest of the lower lake.

Results of statistical analyses were retransformed back to the number of shrimp per photograph by the reverse of equation (1):

$$x = \text{antilog } y - 1 \qquad (2)$$

where y = the transformed data. Shrimp per photograph was then converted to shrimp per square meter by multiplying by 12.077. Geometric means were calculated by this $\log_e$ transformation of data and used in estimating the shrimp density instead of the arithmetic mean, which is easily distorted by the skewed nature of the distribution.

RESULTS

Forebay

Shrimp were counted from 100 photographs taken in the forebay. From these samples, the geometric mean of the population was estimated at 32 shrimp per square meter. The 95-percent confidence interval was 19 to 52 shrimp per square meter. Variability between photographs

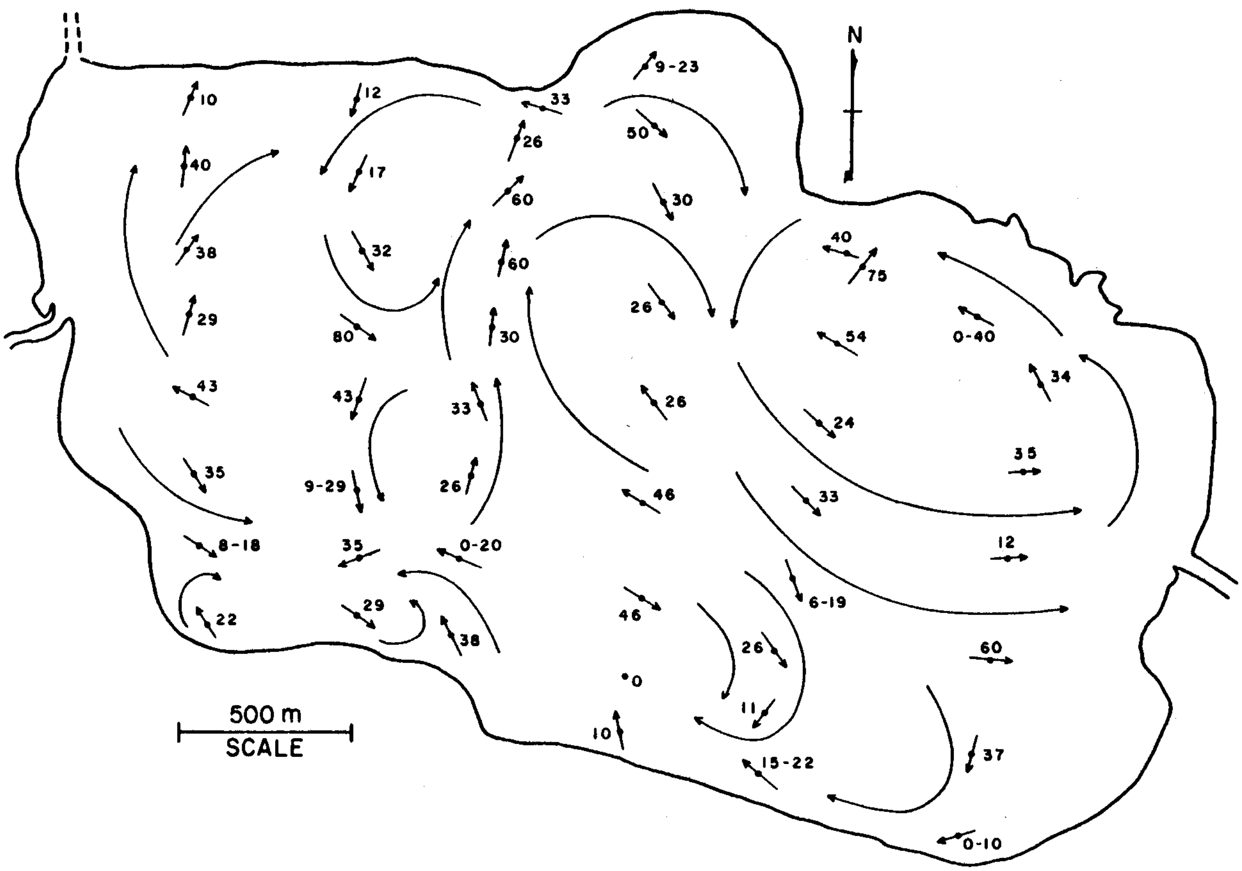

Figure A-16.—Under-ice currents on lower lake on Feb. 18, 1981. Current speeds are given in cm/min.

was high, ranging from 0 to 552 shrimp per square meter. Variability between trawls was also high with trawl density estimates ranging from 13 to 57 shrimp per square meter. The shrimp density in the forebay was significantly different from either the upper or lower lake (95 percent probability). Assuming the geometric mean density is representative of the entire forebay, about 35 million shrimp have been entrained and survived:

(32 shrimp per square meter)(1 092 690 m^2)
[area at surface elevation 2938.3]

Upper Lake

Shrimp were counted from 139 photographs taken in the upper lake. The geometric mean was calculated at 102 shrimp per square meter. The 95-percent confidence interval was 71 to 142 shrimp per square meter. Shrimp densities were again found to be quite variable between photographs, ranging from 12 to 324 shrimp per square meter. Shrimp density estimates per trawl (80 to 123 shrimp per square meter) were less variable in the upper lake than in the forebay. The shrimp density in the upper lake was not significantly different from the lower lake but was significantly different from densities in the forebay (95-percent probability). A population estimate of shrimp in the upper lake was calculated at 253.1 million:

(102 shrimp per square meter)(2 481 000 m^2)
[area at surface elevation 2801.1.]

Lower Lake

Of the five trawls taken in the lower lake, only three could be used to estimate shrimp densities. Trawl "I" (fig. A-18) was conducted where a dense growth of epipelagic algae made the shrimp impossible to see, and trawl "G" was unusable due to turbidity in the area trawled. Therefore, only 103 photographs were used in estimating the shrimp density. From these samples, a geometric mean of the shrimp population was estimated at 112 shrimp per square meter with a 95-percent confidence interval of 74 to 165 shrimp per square meter. Again, density estimates between photographs was high, ranging from 24 to 288 shrimp per square meter. Low variability was found between the density estimates of the

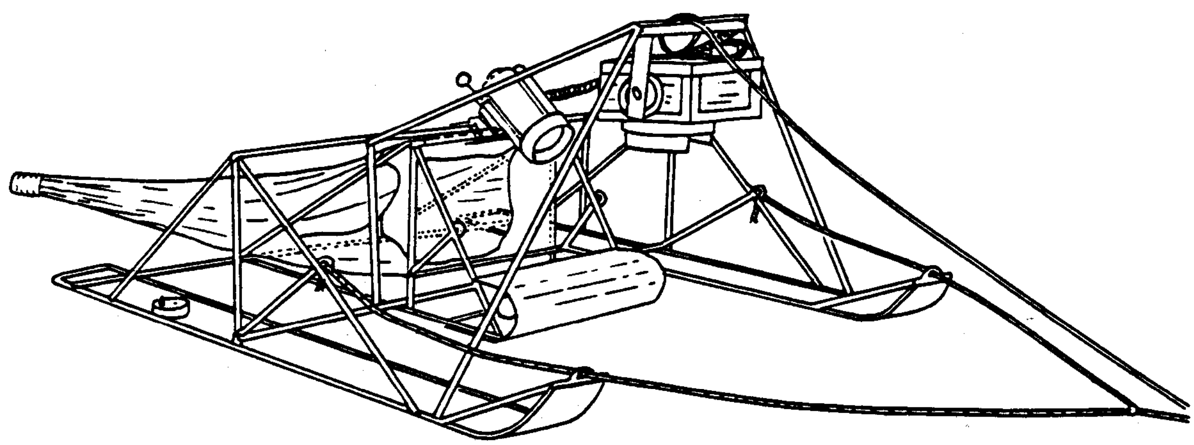

Figure A-17.—Bottom sled trawl used in the Twin Lakes study. Camera equipment and removable net-scoop assembly attached.

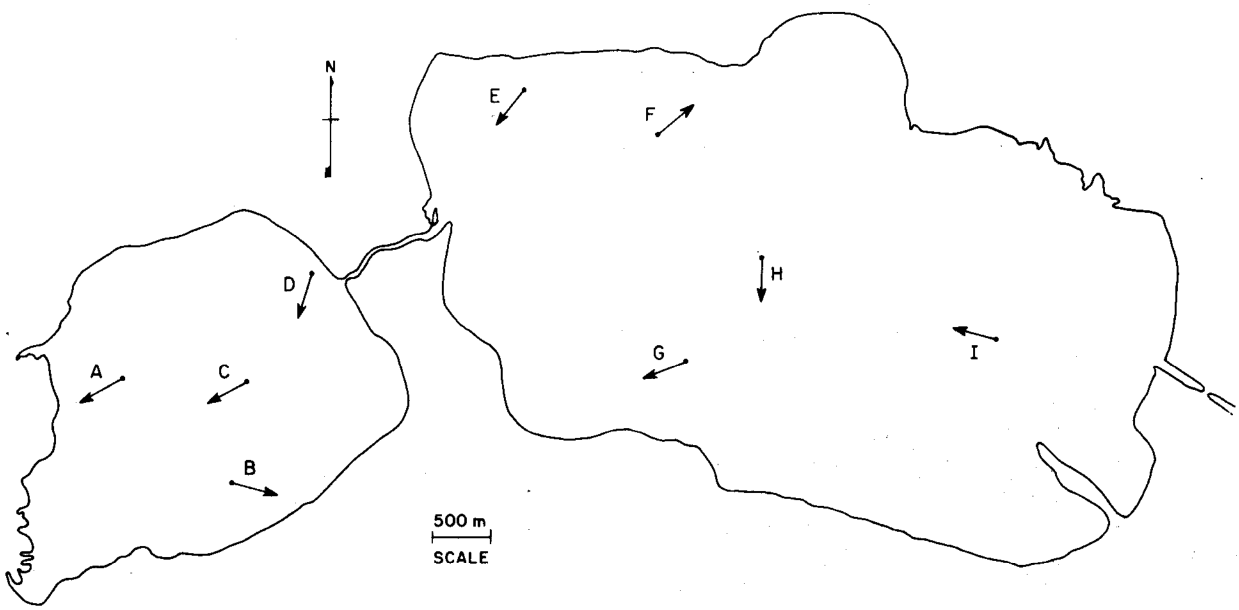

Figure A-18.—Map of Twin Lakes indicating the position and direction of nine phototrawls used to estimate mysis shrimp density.

three trawls with geometric means ranging from 99 to 120 shrimp per square meter. Shrimp densities in the lower lake were not significantly different from the upper lake but were significantly different from densities in the forebay (95 percent probability). Shrimp density in the vicinity of the powerplant (trawl "E", fig. A-18) was not significantly different from the shrimp density in other parts of the lake (95 percent probability). Assuming the geometric mean of these 103 photographs was representative of the lower lake, a population estimate of the shrimp would be 795.4 million:

(112 shrimp per square meter)(7 102 000 m^2)
[area at surface elevation 2801.1]

DISCUSSION

Forebay

The shrimp population in the forebay has grown from no shrimp, when the forebay was drained in the summer of 1979, to an estimated 35 million by the fall of 1981. It is likely this population will continue to grow when the powerplant begins

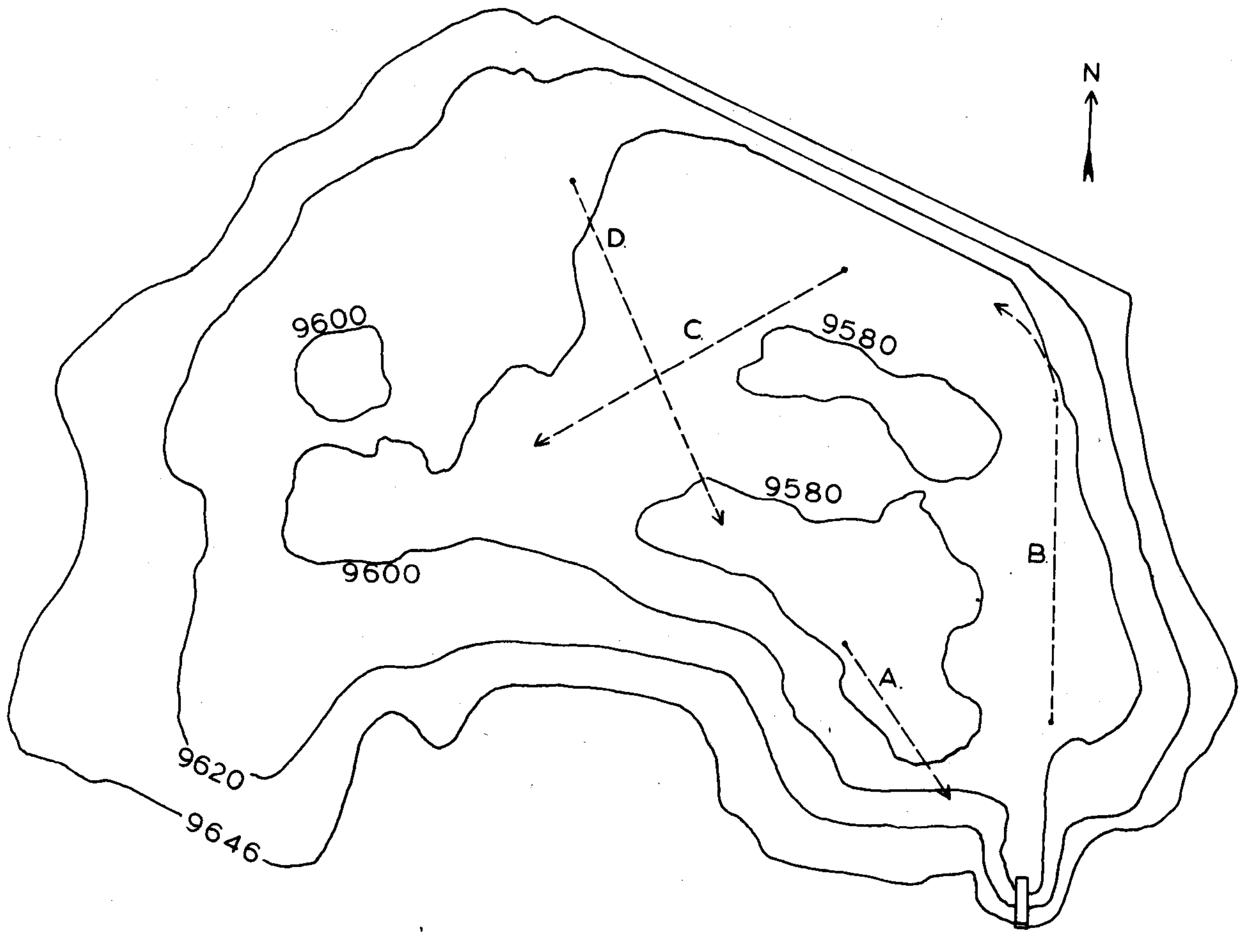

Figure A-19.—Map of forebay indicating position and direction of four phototrawls used to estimate mysis shrimp density.

daily pump-generation cycles. Shrimp seen in the photographs were believed to be alive since recently killed shrimp appear opaque in the photographs. We have some evidence from previous photographs that shrimp have been killed in the passage through the powerplant. This will be investigated further during the summer of 1982.

High variability between samples was noted in the forebay, caused by the strong tendency for shrimp to clump. For some unknown reason, clumping was more pronounced in the forebay than in either the upper or lower lake, as noted by the extreme variability between photographs; that is, 0 to 522 shrimp per square meter.

Upper Lake

A substantial shrimp population existed in the upper lake. The density of 102 shrimp per square meter was not significantly different from the lower lake. Since the powerplant does not presently draw water from the upper lake, the shrimp should not be affected by powerplant operation. The shrimp may, however, be subjected to the same population pressures once water is backed up behind the new dam that was built in 1979-80 below the lower lake, and once the connection between the two lakes becomes wider and less distinct.

Lower Lake

The lower lake had the highest shrimp density, 112 shrimp per square meter, of any of the three bodies of water studied. A dense growth of algae on the eastern end of the lake hampered the use of the phototrawl. Future population estimates in this area may need to be made with the net trawl.

Trawling in front of the powerplant did not show significantly higher shrimp densities than in other areas of the lake. It appears that the powerplant has not yet had an "attractant" influence on the shrimp. It should be noted that powerplant operation has so far only involved irregular testing and the situation may change with daily operation.

RECOMMENDATIONS FOR PHASE II (MONITORING) INVESTIGATIONS

Because of delays in the on-line power production at the powerplant, we were unable to do as much testing of the sampling devices as originally planned during Phase I of our effort. Consequently, much of the testing phase of the study will overlap into Phase II. Our success with Phase II monitoring will be largely dependent on establishment of a routine operating schedule at the powerplant.

APPENDIX B

TWIN LAKES — MT. ELBERT PUMPED-STORAGE STUDIES

1981
Annual Progress Report

Submitted to the

Bureau of Reclamation
under Contract No. 1-07-81-V0188

by

Thomas P. Nesler
Wildlife Researcher B

Research Section
Division of Wildlife
Colorado Department of Natural Resources
Fort Collins, Colorado

May 5, 1982

TWIN LAKES CREEL SURVEY

Creel surveys were completed on Twin Lakes during the May to September open-water season, and on the lower lake only during the January to March ice-fishing season. The data collected from these surveys represent a transitional phase in this study since the powerplant began operation on an irregular basis in late August. While the peak-power demand operating principle of pumped-storage facilities implies a certain amount of irregularity in their operation, the Mt. Elbert unit was not committed as an "on-line" facility for on-call power generation during this study year. Further testing of the powerplant and down time for repairs or maintenance contributed to the uncertain operating schedule. No significant impacts in terms of fish mortality or water quality were observed with the initial operation of the powerplant, which coincided with the last month of the open-water creel survey (September), so this year's open-water creel survey data was expected to conform to the characteristics of the Twin Lakes fishery indicated by the preoperational phase of the study. Analyses of the 1981 creel survey data has shown this to be true. Operation of the Mt. Elbert unit during the winter ice-fishing creel survey appeared to have the greatest impact upon the ice layer of the lower lake, which in turn affected fishermen use.

Open-Water Creel Survey (May-September)

Estimates of fishermen hours and harvest for the two lakes indicate the characteristics of the fishery remain relatively unchanged, see table 1. Fishermen effort and harvest were nearly three times greater on the lower lake compared to the upper lake. Shore fishermen accounted for 86 and 87 percent of the total fishermen hours and 89 and 92 percent of the total harvest on the upper and lower lakes, respectively. The estimate of total fishermen hours for the lower lake was

Table 1. — *Fishermen hours and harvest estimates for Twin Lakes for the 1981 open-water season*

	Fishermen effort			Harvest		
	Shore	Boat	Total	Shore	Boat	Total
			Lower Lake			
May	8,390	2,119	10,509	2,469	260	2,729
June	11,984	1,976	13,960	5,817	297	6,114
July	18,826	2,543	21,369	5,284	781	6,065
Aug.	20,655	2,192	22,847	8,062	409	8,471
Sept.	11,070	2,020	13,090	4,429	553	4,982
Total	70,925	10,850	81,775	26,061	2,301	28,362
(CV)[1]	(8)	(10)	(7)	(10)	(13)	(9)
			Upper Lake			
May	1,912	270	2,182	699	40	739
June	6,178	824	7,002	1,583	0	1,583
July	8,050	1,220	9,270	1,633	266	1,899
Aug.	4,915	979	5,894	1,520	319	1,839
Sept.	3,162	549	3,711	970	144	1,114
Total	24,218	3,843	28,061	6,404	767	7,171
(CV)	(10)	(15)	(10)	(13)	(27)	(13)

[1] Coefficients of variation (CV) expressed as percent of total estimate.

not significantly different from the 1973-79 estimates and the lower lake harvest was significantly greater than that estimated for 1974 only, see table 2. The upper lake estimate of fishermen hours was significantly greater than the estimates for 1974 and 1979. The upper lake harvest estimate was one of the lowest during the study period, and was significantly lower than the harvest estimates for 1973, 1975 and 1977. Coefficients of variation for the 1981 estimates were similar to those for previous years' statistics. Catch rates for shore and boat fishermen on the lower lake were 0.37 and 0.21 fish per hour, respectively, which were within the ranges exhibited by the catch rates estimated in previous years. Catch rates for shore and boat fishermen on the upper lake were 0.26 and 0.20 fish per hour, respectively, which indicated that the downward trend exhibited for both fishermen types in 1977 and 1979 has continued. Species composition of the harvest again showed rainbow trout comprised 82 to 99 percent of the harvest for all categories, see table 3. Lake trout were again second in relative abundance though brown trout were caught more frequently in the upper lake in 1981 compared to previous years. Shore fishermen accounted for 90 percent or more of the rainbow trout harvested, and 50 to 94 percent of the brown trout harvested. Boat fishermen accounted for 48 and 74 percent of the lake trout harvested in the upper and lower lakes, respectively. About 87,000 creel-size trout were

Table 2. —*Estimates of total fishermen hours and harvest for open-water seasons during the 1973-81 preoperational study at Twin Lakes*

	Lower Lake		Upper Lake	
	Hours	Harvest	Hours	Harvest
1973	89,820	26,627	29,036	12,457
1974	79,385	19,955	20,800	7,014
1975	79,183	32,496	29,139	11,761
1976	--	--	--	--
1977	66,673	23,534	24,743	11,239
1978	--	--	--	--
1979	70,996	25,423	19,719	6,413
1980	--	--	--	--
1981	81,775	28,362	28,061	7,171

stocked into Twin Lakes during the open-water season in 1981. Almost 19,000 of these fish were marked with a finclip to evaluate the return rate to the fishermen. Three marked stocks of fish were released in the lower lake, and these fish were returned in the harvest at rates of 41 to 45 percent. One marked stock of fish was released in the upper lake and returned in the harvest at a rate of 39 percent.

The similarities between the 1981 data and that from previous years indicate the 1981 open-water season was typical for the lower lake fishery, though on the high side of the average

Table 3. — *Species composition of total harvests at Twin Lakes during the 1981 open-water season*

	Shore		Boat		Total	
	No.	%	No.	%	No.	%
			Lower Lake			
Rainbow trout	25,885	99	1,898	82	27,783	98
Lake trout	133	1	369	16	502	2
Brown trout	33	--	34	2	67	--
Brook trout	10	--	0	--	10	--
			Upper Lake			
Rainbow trout	6,107	95	661	86	6,768	94
Lake trout	102	2	94	12	196	3
Brown trout	175	3	12	2	187	3
Brook trout	20	--	0	--	20	--

fishermen use and harvest. This also describes fishermen use on the upper lake, although the upper lake catch rates and harvest have remained on the low side of the range of estimates provided by the preoperational creel surveys.

Winter Ice-Fishing Creel Survey (January-March)

The creel survey of the ice fishermen was conducted from January 1 to March 31, 1981. No sampling was possible in December 1981 since a complete ice cover was not maintained on the lower lake until December 22. The ice cover on the lower lake was 5 days later than that of the upper lake, and may have been the result of operation of the Mt. Elbert powerplant during mid-December. During December 11-16, the powerplant pumped for 19 hours and generated for almost 34 hours. On December 18 and 21, the powerplant generated for 2 and 13+ hours, respectively. During this mid-December period, the western two-thirds of the lower lake was open water and the eastern one-third of the lake was ice covered. This condition corresponded to the pattern of under-ice currents measured at the lower lake on February 20, 1982, during powerplant generation, when a uniform, counterclockwise circulation pattern including the western two-thirds of the lake was observed. Current speeds ranged from 2.5 to 4.7 m/s along the western shore, and from 0.7 to 1.4 m/s in the west central half of the lake. Details of this circulation pattern are reported by Maiolie and Bergersen of the Colorado Coop Fish Research Unit in their January - March quarterly report to the Bureau of Reclamation. The whole-lake mean current speed created by the February 20 under-ice currents was about 2.7 times greater than the mean current speed observed in February 1981 without powerplant operation. It is possible that the increased water movement caused by the powerplant flows in December retarded the formation of a stable ice cover on the lower lake. This effect on ice formation at Twin Lakes will reduce the length of the ice-fishing season.

The creel survey estimates for the January to March period in 1982 indicate ice fishermen spent 7,188 hours on the lower lake and harvested 763 fish for a catch rate of 0.11 fish per man-hour, table 4. Fishermen success was greatest in January, as indicated by the catch rates, and declined steadily through March. Powerplant operation had a noticeable effect on the lake's ice layer, causing fracturing of the open ice layer and buckling near the shoreline. During extended periods of powerplant generation, large pockets of deep slush were created on the ice surface and water was forced up through the ice near the shore, eroding large holes and creating a moat of standing water up to 300 mm or more in depth around the lake's edge. These conditions impeded fishermen access onto the ice surface and restricted travel over the ice with motor vehicles. Despite these problems, fishermen effort was not reduced relative to previous seasons. Comparison of the estimate of total hours in 1982 with that estimated for the six previous winter seasons shows the 1982 estimate to be the second highest recorded, table 5. The number of fish harvested in the 1982 winter season was the highest recorded but, in terms of fishermen success, the catch rate ranked only fourth or mid-range.

Lake trout comprised 97 percent of the fish checked (150/154), and exhibited a mean length

Table 4. — *Winter creel survey estimates for lower lake in 1982*

Month	Weekdays	SE[1]	Weekends	SE	Total	SE
			FISHERMEN HOURS			
Jan.	935	± 331	1,256	± 236	2,191	± 406
Feb.	1,126	± 210	1,590	± 142	2,716	± 253
Mar.	1,225	± 359	1,056	± 177	2,281	± 400
Total	3,286	± 531	3,902	± 328	7,188	± 624
			FISH HARVESTED			
Jan.	113	± 52	176	± 46	289	± 69
Feb.	162	± 82	132	± 44	294	± 93
Mar.	87	± 40	93	± 28	180	± 49
Total	362	± 105	401	± 70	763	± 126
			CATCH RATES[2]			
Jan.	0.121	±0.037	0.140	±0.027	0.135	±0.022
Feb.	.144	± .069	.083	± .027	.096	± .024
Mar.	.171	± .027	.088	± .022	.082	± .018
Total	.111	± .026	.106	± .014	.107	± .012

[1] SE = standard error
[2] Catch per man-hour

Table 5. — *Winter creel survey estimates for lower lake, Jan. - Mar., 1974—82*

	1974	1975	1976	1977	1978	1979	1982
Hours	5,000	5,543	7,389	6,875	5,321	3,314	7,188
Harvest	621	749	734	525	481	357	763
Catch rate[1]	0.124	0.135	0.099	0.076	0.090	0.108	0.107

[1] Catch per man-hour

of 460 mm. The largest lake trout checked was 690 mm in length though several lake trout from 760 to 860 mm were reported but not observed. Over 17 percent of the lake trout checked were 510 mm in length or greater. The 1982 mean length of lake trout harvested ranked second compared to previous years and was exceeded only by the 480-mm mean length estimated in the 1974-75 winter season. The percentage of lake trout harvested in 1982 exceeding 500 mm reverses a recent declining trend.

At this point these results do not demonstrate that pumped-storage power generation has had a positive impact upon the magnitude or size characteristics of the lake trout harvest. The 1982 winter catch rate indicates the ice fishermen's success was typical, relative to the preoperational estimates. The relative increase in the lake trout mean size and increased percent of fish exceeding 500 mm in length are indications of the harvest being dominated by one or several age groups of lake trout whose growth pattern was not influenced by powerplant operation until recently. Operation of the Mt. Elbert unit may influence the estimates of fishermen use (hours) by:

(1) retarding the formation of a stable ice cover in December, and

(2) accelerating the break up or deterioration of the ice cover in March.

This would, in effect, shorten the duration of the ice-fishing season, as is possibly indicatd by this past winter's data.

LAKE TROUT POPULATION STUDIES

The standarized gill net sampling of lake trout was resumed at Twin Lakes in November, and

114 lake trout were captured in 16 nets set overnight. The fish ranged from 191 to 762 mm in length and from 53 to 3175 g in weight. The mean number of lake trout per net and the mean length of the lake trout captured show relative increases in these indices for the November 1981 sample compared to November samples in previous years, tables 6 and 7. These indices indicate that the lake trout are characteristically more abundant in the lower lake compared to the upper lake, and are more abundant at the deep-water stations (>15m) compared to the shallow-water stations in the lower lake. The mean length of lake trout captured at the shallow stations is characteristically larger than that observed for lake trout captured at the deep stations. Other fish captured in the nets included 52 white suckers (mean length 352 mm), 7 longnose suckers (mean length 181 mm), 8 rainbow trout (mean length 299 mm), 2 brown trout (315-403 mm) and 1 brook trout (205 mm). The lake trout data demonstrate the influence of year class dominance in the population, and provide the basis for the explanation of the winter creel survey results.

Table 6. — *Relative abundance of lake trout in Twin Lakes according to November gill net samples*

Year	Total no. captured	Mean no. lake trout per net: Total	Deep stations	Shallow stations
		Lower Lake		
1974	101	7.2	8.2	5.4
1975	93	6.6	7.9	4.4
1976	--	--	--	--
1977	60	4.3	5.0	3.0
1978	--	--	--	--
1979	81	5.6	7.3	2.4
1980	--	--	--	--
1981	108	8.3	11.3	3.6
		Upper Lake		
1974	16	5.3	5.3	--
1975	19	6.3	6.3	--
1976	--	--	--	--
1977	3	1.0	1.0	--
1978	--	--	--	--
1979	3	1.0	1.0	--
1980	--	--	--	--
1981	6	2.0	2.0	--

Potential loss of fish, especially lake trout, through the outlet works at Twin Lakes has been a concern in the past. With the alterations in the morphology of the lakes with the construction of the new dam and the proposed diversion of Homestake-Otero Project water from the Arkansas River using an accessory outlet spur from the new dam, the escapement of game fish from the lakes was again investigated. The objective was to determine if significant numbers of lake trout were utilizing the new lake area existing between the new and old dam structures, and whether lake trout were leaving the lake and existing in Lake Creek. A significant loss of lake trout, or all game fish, in this manner would portend an irrecoverable loss of fish to the Homestake Diversion. Fish sampling with gill nets was conducted in the new lake area in late April and May, and was conducted with electrofishing equipment in Lake Creek in June. Only one lake trout, 210 mm, was captured. The majority of fish captured at each effort were brown trout. Fish captured in the new lake area included 71 brown trout (mean: 310 mm; range: 166-425 mm), 9 rainbow trout, 2 cutthroat trout, 1 brook trout, 30 white suckers, and 20 longnose suckers. It was apparent that the brown trout were utilizing the mysis shrimp heavily as food, and that the fish did not reside long in the new area since none of the 38 fish tagged and released in April were recovered in May. In Lake Creek, fish captured included 76 brown trout (mean: 230 mm; range: 110-370 mm), 6 rainbow trout, 2 brook trout, 39 white suckers, 13 longnose suckers, and 1 lake trout. These and other results suggest that lake trout escapement en masse from reservoirs in a singular, short-term event or that survival time of escaped fish in the stream environment is short.

Table 7. — *Mean lengths in millimeters of lake trout sampled at Twin Lakes by gill nets in November*

Year	Shallow stations	Deep stations	Total
1973	424	393	396
1974	397	323	334
1975	414	328	348
1976	--	--	--
1977	445	378	395
1978	426	360	369
1979	373	350	353
1981	459	386	393

MT. ELBERT POWERPLANT ENTRAINMENT/MORTALITY STUDIES

Prototype designs and construction of sampling devices for the Mt. Elbert forebay and tailrace were essentially completed. Some preliminary testing of the forebay equipment was possible, but the results were uncertain since some doubt concerning the effectiveness of the gear existed. Only the partial remains of a single brown trout have been recovered with the forebay net.

Visual checks in the forebay, primarily along the shoreline, revealed only three certain mortalities. Two small lake trout and a longnose sucker, all severed at the head or trunk, have been recovered. Several air bladders were observed at night on the water surface during pump-back operations. Sampling with gill nets for about 240 net-hours prior to any pump-back operation resulted in no fish captured. One fish, 50 to 80 mm long, was observed in the forebay riprap at this time. For the first pump-back test, which spanned about 2 hours of operation, gill nets were set prior to the test just outside the area of the trash racks in the forebay. Again, no fish were captured. Visual observation of the forebay shoreline revealed no fish mortalities and only 2 to 3 live fish.

The first significant numbers of fish captured in the forebay occurred in mid-November when 52 were taken. Most of these were taken by two nets set at the points of the riprap defining the gatehouse bay from the main body of the forebay. Four other gill nets set along the shoreline of the forebay in opposite corners of the reservoir captured few fish. Table 8 summarizes the catch data and shows that fish up to 410 mm in length may pass through the turbines unharmed. Three of the fish captured, 1 rainbow trout (290 mm long) and 2 white suckers (210 and 360 mm long), exhibited injuries to the caudal peduncle or fin, presumably resulting from passage through the turbines. Of particular interest was the observation that 12 of the 15 rainbow trout captured were literally gorged with mysis shrimp, and exhibited excellent body condition. Six of these rainbow trout were finclipped fish from the July stocks in the lower lake. One of the larger lake trout and the largest rainbow trout also had fish in their stomachs. These observations suggest that lake trout and particularly rainbow trout are feeding on mysis and small fish entrained in either the pump-back or generation flows. The one rainbow trout with a severed caudal fin had an empty stomach.

While several tests and operation of the powerplant generation mode have been completed, no fish mortalities associated with this operation have been observed. Some time was spent sampling currents and plankton within the tailrace channel during generation. Qualitative observation of the plankton samples showed significant numbers of *Daphnia* entrained in the flow.

Table 8. — *Catch data for November gill net sampling of Mt. Elbert Forebay*

Species	No.	Mean length, mm	Range, mm
Lake trout	2	410	--
Lake trout	4	210	190-230
Rainbow trout	15	300	230-370
Brook trout	1	230	--
Brown trout	1	250	--
White sucker	14	250	160-370
Longnose sucker	15	190	160-240

PLANNED WORK—1982-83

The stratified random creel survey and the standardized gill net sampling for lake trout provide the information base that characterizes the Twin Lakes fishery and lake trout population. The characterization of these attributes of Twin Lakes constitutes the preoperational data base to which subsequent operational data will be compared, and permits the determination of the effects of powerplant operation upon the sport fishery and lake trout population. For these reasons, these two sampling techniques will be repeated in 1982-83. Detailed reporting of the relative abundance, distribution, size and age composition, growth and mortality rates, and feeding habits of the lake trout population covering data collected from 1973 to the present will be completed in 1982-83.

Enlargement of Twin Lakes behind the new dam did not occur as expected in 1981-82. As a result, the increased stocking level scheduled for the proposed increase in surface area has been reduced from 87,000 creel-size rainbow trout stocked in 1981-82 to 70,000 for 1982-83. Some question remained in the final report covering the preoperational creel survey concerning a percentage of the rainbow trout harvest in the lower lake that could not be accounted for by the projected estimates of marked and unmarked rainbow trout stocked in a given open-water season. These rainbow trout were considered to be either immigrants from the upper lake stocked at the same time, residual fish from previous years' stocking, or naturally-produced fish. An attempt will be made to account for the origin of these fish to clarify the components of the rainbow trout harvest and the percent return to the creel of stocked rainbow trout. This will be accomplished by resuming marking by finclipping of all rainbow trout stocked into Twin Lakes. All unmarked rainbow trout encountered in the creel survey will be processed for length, weight, and age data, and compared to similar data for the marked rainbow trout. Electrofishing of segments of the near shore area of the lower lake will be conducted, if possible, prior to the first stocking of marked rainbow trout in May 1982 to acquire an adequate sample of unmarked rainbow trout currently inhabiting the lake, and acquire some idea of the relative abundance of these fish. A marked and recapture population estimate of the size of the near shore populations of rainbow trout and other fish species as encountered will be attempted during this sampling. A nearly complete absence of rainbow trout in the areas sampled by the lake trout gill nets, which includes most of the lake bottom except the near shore zone, is evident. Additional sampling in the open water area of the lakes will be done to determine the relative abundance of rainbow trout in this lake zone, and clarify the distribution of rainbow trout in the lakes.

Yearly fall stocking of hatchery-raised, fingerling lake trout as available was implemented to support the natural recruitment within the lake trout population. The contribution of these fish to the population stock and the fishery appears to be negligible from the evidence of most tag return data, but stocking of these fish will continue through the remaining study period to prevent a change in this variable from confusing the impact analyses in the event of a decline in the lake trout abundance due to powerplant operation. The effectiveness of this stocking will be evaluated by the continued marking of the fingerling fish by finclipping a sizeable percentage of the stock and/or pigment spray marking the entire stock if the necessary equipment is available. Of the 46,000 fingerling lake trout stocked in September 1981, 10,000 were given an adipose finclip. All live lake trout collected in Twin Lakes from the various sampling efforts will be identified by colored, numbered floy tags before being returned to the water. These floy tags will replace the use of finclipping, and subsequent tag returns will provide supplementary data on fish age, growth, mortality, and lake movements.

Considering the preliminary state of the Mt. Elbert Forebay sampling gear, sampling of the forebay with surface and bottom gill nets and near shore electrofishing will be continued to establish the relative abundance and length frequency distribution of fish species entrained in the powerplant flows. These results will supplement the direct powerplant flow sampling, and provide cross check data about relative vulnerability to entrainment size selective mortality of the various fish species present in Twin Lakes.

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